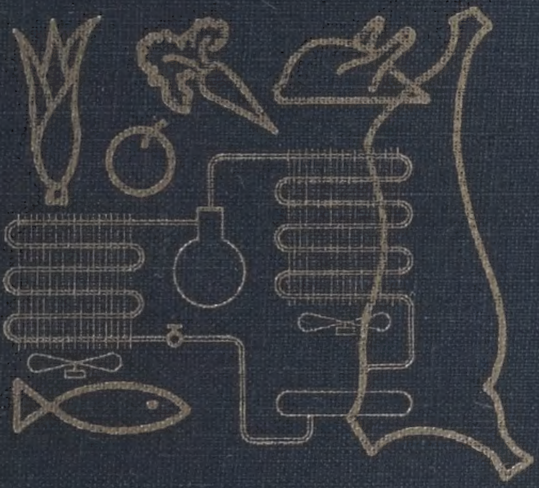

COLD AND FREEZER STORAGE MANUAL

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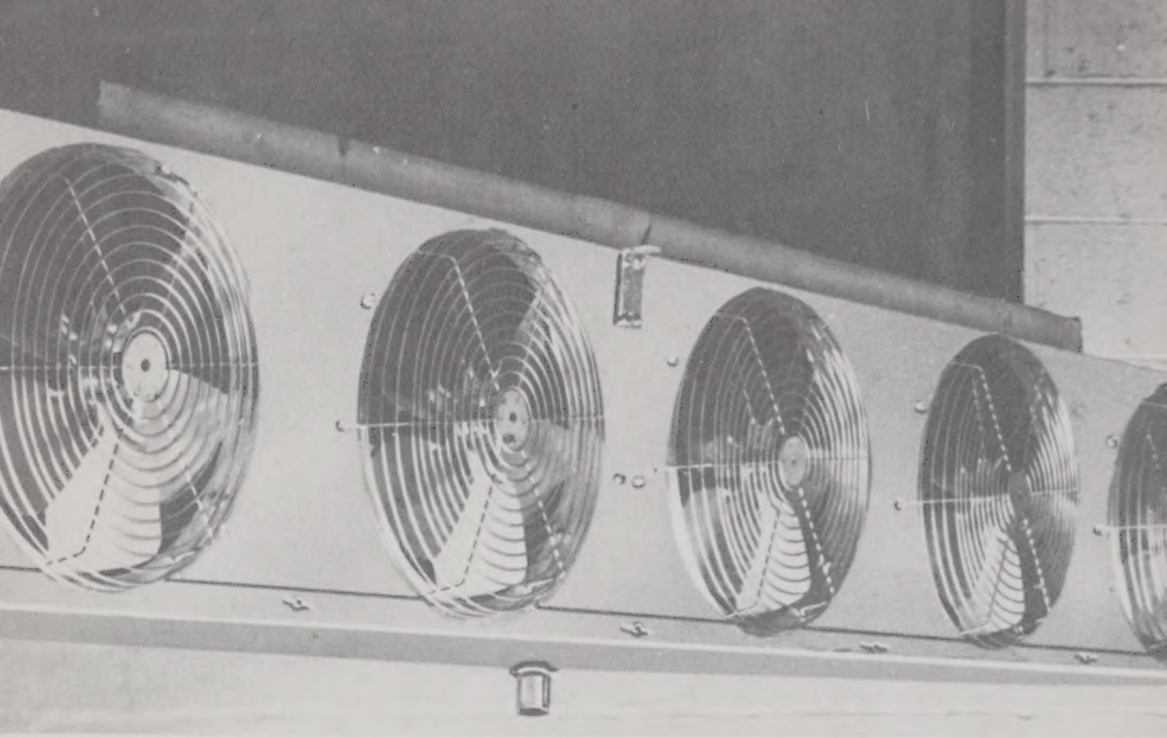

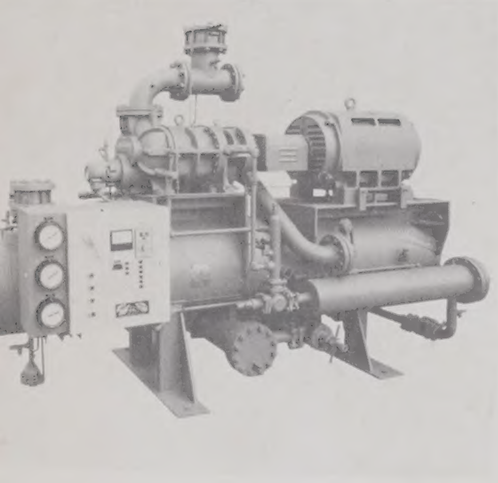

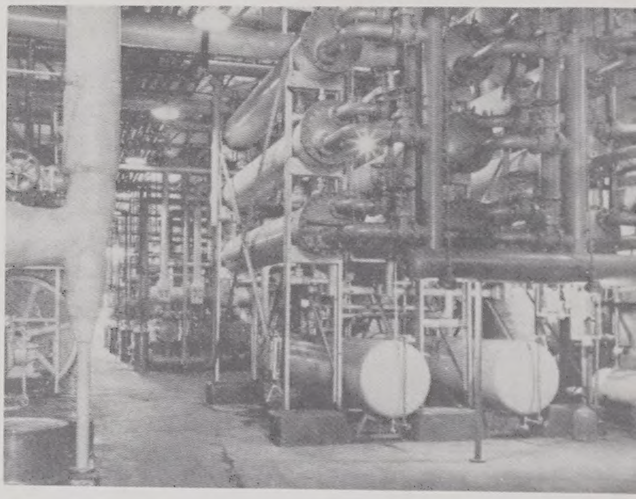

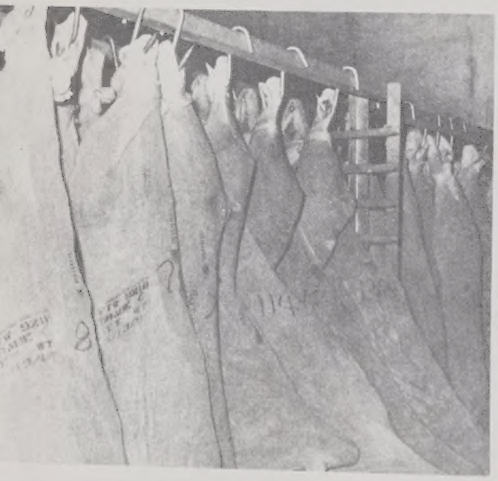

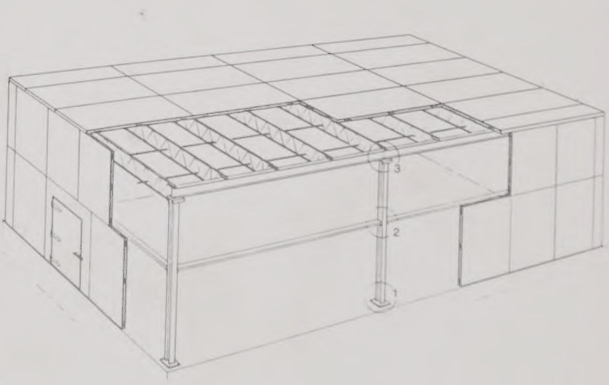
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COLD AND FREEZER STORAGE MANUAL

SECOND EDITION

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Frontispiece courtesy of: Bohn Heat Transfer Division, top; Freezing Equipment Sales, Inc., center left; Alford Refrigerated Warehouses, center right and bottom left; Master-Bilt Products, bottom right.

Library of Congress Cataloging in Publication Data

Hallowell, E. R.
Cold and freezer storage manual.

Earlier ed. by W. R. Woolrich and E. R. Hallowell published in 1970.
Includes index.
1. Cold storage. I. Woolrich, Willis Raymond, 1899-
Cold and freezer storage manual. II. Title.
TP372.2.W66 1980 664'.0285 80-21010
ISBN 0-87055-366-6

Printed in the United States of America

CFTRI-MYSORE
16452
Cold and freezer

Preface

W.A. Woolrich, coauthor of the first edition of this manual, died in February, 1977. This edition is being written after his death. Due to changing concepts of cold and freezer storage refrigeration and energy conservation, a complete revision of the original text seems to be indicated. This volume will attempt to introduce information and ideas consistent with economies that are now demanded in a world beset with uncertainties of future power sources and energy costs.

Since the advent of this manual in 1970, rather startling changes have occurred in the concept of the supply of energy. The world has become aware of the fact that available energy from the normal sources is not infinite and that there are very definite indications that it will become a very scarce and expensive commodity. The development of new sources of energy will surely take place, but in the intervening time, the efficient use of energy must be a prime consideration. Users of energy can no longer afford to be careless or wasteful. Increased power costs, as well as possible forced conservation, will dictate the use of more efficient systems. Since no startling refrigeration developments appear imminent, it becomes necessary to utilize existing components more wisely in the future than was done in the past.

One of the objects of the second edition will be to stress design concepts which will allow better and more efficient use of equipment, insulation and other facets influencing operational costs of refrigerated spaces. In most instances, this will mean a higher first cost of equipment compared to some of the standard designs now in use. However, with rapidly increasing energy costs, the higher equipment costs may prove to be the most economical in the overall concept.

Many of the trends in refrigeration design, when viewed in the light of the past forty or fifty years, would indicate that in recent years, system efficiencies have been sacrificed in the interests of a lowered first cost. This has been particularly true through the era of low cost power. The cost of power was not high enough to warrant highly efficient equipment, which was costly to buy, and energy supplies seemed limitless. This trend must now be reversed since power costs are constantly increasing and since it is being discovered that energy sources, at least those which we are presently using, are not limitless. The equipment exists. It is only a matter of choosing the correct components to fit the job.

Over the years, cold and freezer storage use has expanded continuously and now represents a very respectable segment of the food and related industries concerned with the processing and distribution of perishables. It is universal and so common that it escapes specific notice except when a breakdown occurs to interrupt its use. It is difficult to imagine the country without refrigeration.

This manual is an attempt to express, in lay language, some of the design concepts for cold storage installations. It is not a technical treatise; but designed to give prospective owners and operators of cold storage facilities, large or small, a better insight into the design aspects that might be expected when constructing new, or modernizing old cold storage warehouses.

The text represents some 45 years of observation and active participation in the refrigeration and cold storage field. Opinions expressed are those gained in this period. It is realized that there may be a great variety of methods used to achieve sound design. Honest opinions will vary greatly regarding the best selection of equipment and systems. This edition is an attempt to put in some order, design practices and equipment selection methods observed through many years in the refrigeration industry.

Both English and metric measurements are indicated in most sections of the text. The complete International System (SI) of units has not been used. Since this volume is intended as a liaison between designers and owners and operators, it is believed that simple metric or English units are better understood at the present writing since the present rate of conversion to SI units is somewhat slow and certainly not fully understood by most individuals (including this writer).

Since this volume is not intended as a text for calculations, only whole numbers will be used where practical. The results will be within an accuracy range which is sufficient for the discussions following.

ELLIOTT HALLOWELL
Dallas, Texas

April 10, 1980

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Section I

Refrigeration and Refrigerants

1

Principles of Refrigeration

The refrigeration system is the life blood of any cold storage operation. A good system can be a great satisfaction; a poor system generates problems. Anyone who contemplates becoming involved in the planning, construction or operation of a cold storage facility should have, at least, a nodding acquaintance with the principles of refrigeration. It is not the intent of this volume to expound on these principles at great length; but rather to supply the reader with enough basic information to allow him to communicate, with some intelligence, with designers and engineers in the understanding and evaluation of equipment offered. There are usually several choices in equipment selection, all of which may be equally good and depend on the desires of the plant designer. Other options may have pecularities that make them desirable for some applications but not for others. Some knowledge of refrigeration is essential to the proper selection of various options that may be offered.

DEFINITIONS

In refrigeration terminology, there are numerous terms used that are germane to the refrigeration industry and may have a somewhat different meaning than that normally assigned to the term. Appendix 1 contains a number of these terms with explanations, and it is hoped in good lay English. There are a few expressions that are frequently used in discussing refrigeration that require a more complete explanation than found in the appendix. The following definitions cover some of these terms which are used frequently in any discussion concerning refrigeration.

Refrigerant

In the compression refrigeration cycle, the refrigerant is a fluid that reacts to heat and pressure in very much the same manner that water reacts when it changes from a liquid to steam by boiling or from a vapor (steam) to a liquid by condensation. The chief difference between water and refrigerants used in cold room operations is that the refrigerant reacts at a lower temperature level than water.

When heat is applied to water, in an open vessel, the water temperature will rise to 212°F (100°C), at which point it will begin to boil and will continue to boil at this temperature until all of the water is boiled into steam. If further heat is applied to the steam, the steam temperature may be raised and this is called superheat. In a like manner, if heat is applied to a refrigerant such as ammonia and at atmospheric pressure, it will boil at −28 F (−33 C). In refrigeration parlance, the term boiling is quite often expressed as evaporation and means the same thing.

Like water, as pressure is increased on the evaporating refrigerant, the temperature at which it evaporates (boils) will be increased. As an example, if the pressure on evaporating ammonia is raised to about 16 psig (1.12 kg/cm^2), the evaporating temperature will be raised to 0°F (−18°C).

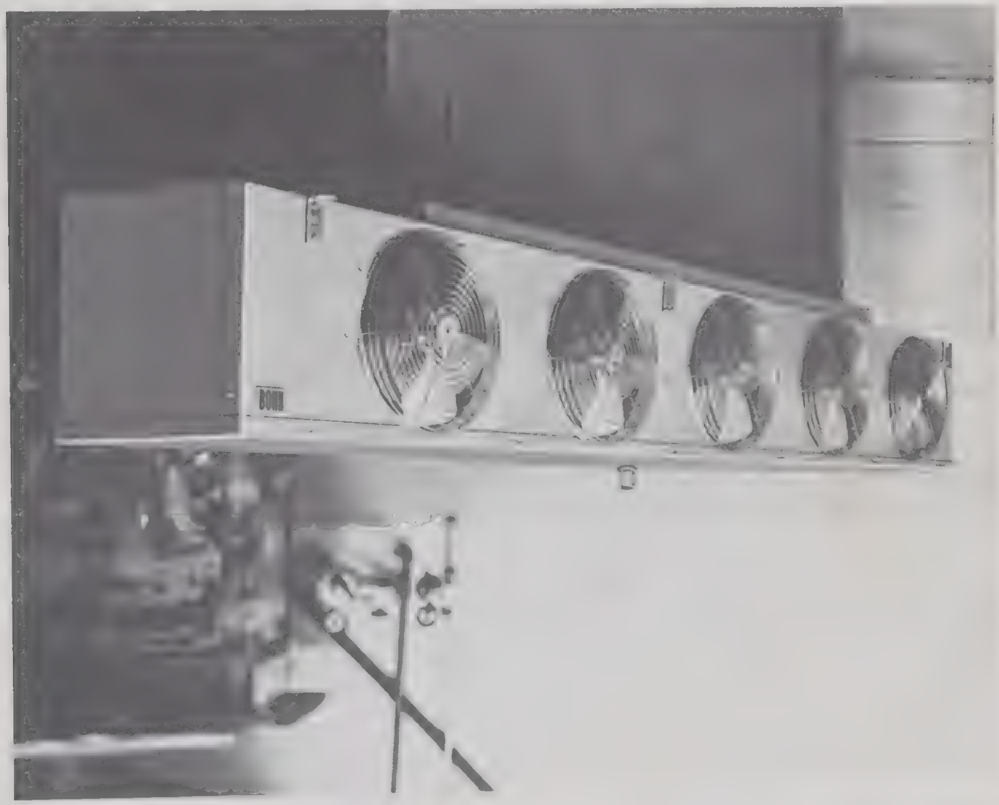
Refrigerants, in the same manner as water, have the ability to be condensed back into a liquid by the removal of heat when they are in a vapor state (steam). The condensation temperature can be controlled as required by varying the pressure on the vapor. This principle is made use of in the compression cycle of refrigeration.

A good refrigerant should have the ability to absorb a high quantity of heat when vaporizing, should operate at reasonable pressures and should be a stable compound throughout the range in which it is used. Some common refrigerants are ammonia and Refrigerants 11, 12, 22, 500 and 502.

The temperature at which a refrigerant will evaporate is predicated by the characteristics of the refrigerant and the pressures imposed on it during vaporization. Each refrigerant has its own properties. Tables and charts are available giving the properties of all common refrigerants and these are used extensively in designing various components of the refrigerating system as well as the complete system itself.

Evaporation – Evaporator

In refrigeration terms, the cooling effect in a cold storage room is obtained by the controlled boiling, or evaporation, of a liquid refrigerant. The pressure at which the refrigerant evaporates is controlled which, in turn, controls the evaporating temperature. The refrigerant is evaporated inside of a pipe coil or other vessel and, in the case of a room cooling coil, room air is forced over the outside of the coil. This fan coil unit is commonly called an evaporator. Heat is transferred from the room to the evaporator by means of the room air which is mechanically forced over the outside of the evaporator surface. The heat is then transferred through the metal of the evaporator to the refrigerant which absorbs the heat by evaporation (boiling). Again, this can be seen as a parallel action to that of water in a boiler being evaporated, or boiled, by the addition of heat; the main difference being that a refrigerant normally acts at a much lower temperature range than water. The term "evaporator" is a logical term to describe a cooling coil since the refrigerant is evaporated within the coil. Fig. 1.1 illustrates a cooling fan coil unit of the type commonly used in cold room cooling.

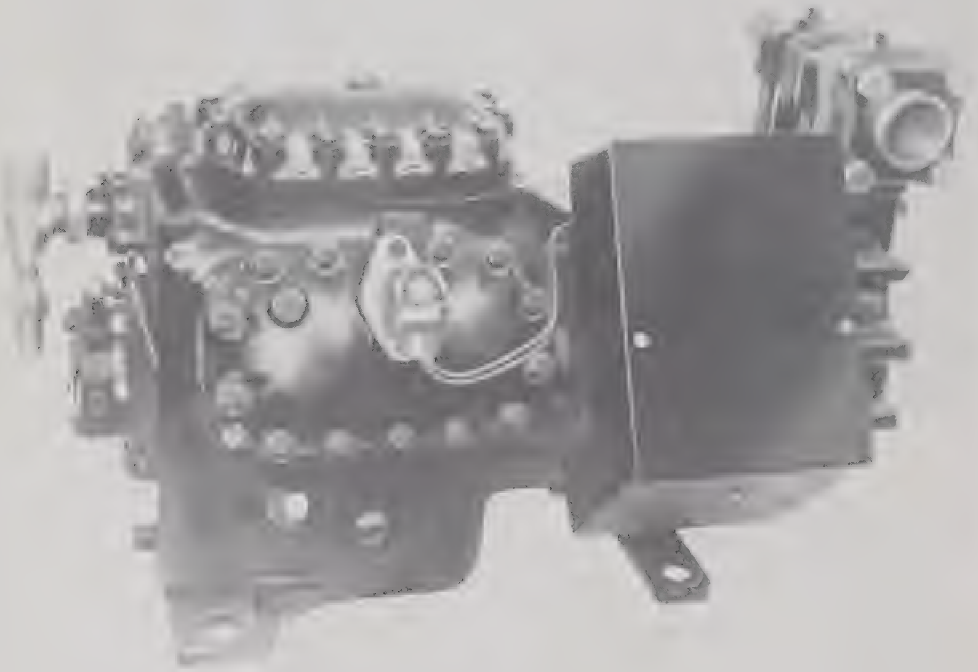


Courtesy Bohn Heat Transfer Division

FIG. 1.1. MULTI-FAN UNIT USED FOR ROOM COOLING. EVAPORATOR COIL IS IN CASING BEHIND FANS. FANS PULL ROOM AIR OVER THE COLD COIL TO COOL THE AIR AND THEN DISCHARGE THE AIR INTO THE ROOM BEING COOLED.

Compression – Compressor

After a refrigerant liquid has been evaporated to produce the required refrigerating effect, it is in the form of a vapor, or gas. Refrigerants, being expensive, cannot be thrown away at this point but must be converted back into a liquid for use again in the evaporator. The first step in this process is the compression of the gas, by means of the refrigerant compressor, from its evaporating pressure to a higher level. Since the refrigerant boiling and condensing temperatures are proportional to the pressure imposed on the refrigerant, the compression of the refrigerant vapor actually raises the corresponding level of the temperature so that the vapor may be condensed back into a liquid by the extraction of heat from an easily obtainable medium such as air or water. Thus, the heat from the cold room is removed at a low temperature level by the refrigerant in the evaporator, the refrigerant being vaporized in the process. The compressor then raises the evaporated liquid (gas) to a higher pressure level where the heat may be removed easily and the vapor condensed into a liquid. The power required to drive the compressor is actually the power to raise the refrigerant from one level of pressure to another higher level and is not equivalent to the work done by the refrigerant. To repeat, heat is removed at a low level, the level is then raised by the compressor and the heat discarded at the higher level. It is from the raising of pressure by the compressor that this recovery and refrigeration cycle is known as the "compression cycle." Fig. 1.2 illustrates a simple refrigeration compressor.

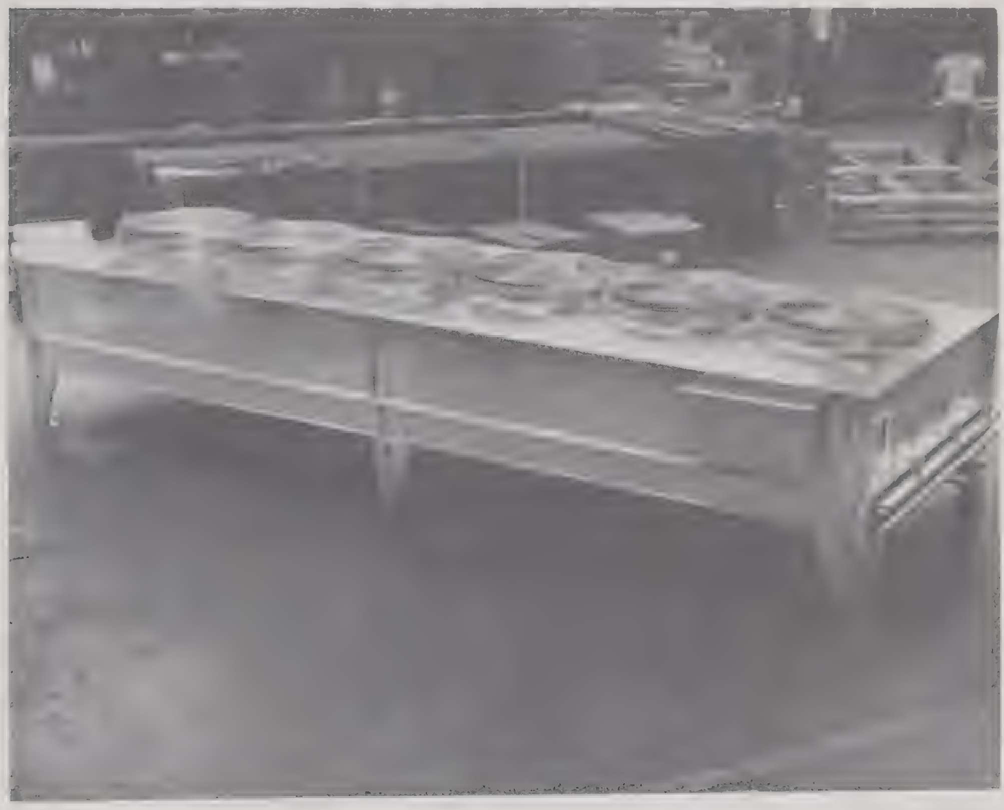


Courtesy Copeland Corporation

FIG. 1.2. SIMPLE MULTI-CYLINDER REFRIGERATION COMPRESSOR OF THE SEMI-HERMETIC TYPE COMPLETE WITH DRIVING MOTOR, JUNCTION BOX AND SERVICE VALVES.

Condensation - Condenser

When the refrigerant vapor is compressed to a higher pressure by the compressor, it flows into another vessel, or set of coils, called the condenser. The elevated pressure, with its corresponding higher temperature equivalent, is high enough so that a medium such as air or water will cause heat from the refrigerant vapor to flow into the medium. The extraction of heat causes the refrigerant vapor to condense back into a liquid form. The condensed liquid refrigerant then normally flows from the condenser into another vessel called a receiver where it is stored for another journey through the evaporator. Fig. 1.3 and Fig. 1.4 show an air cooled and water cooled condenser, respectively.

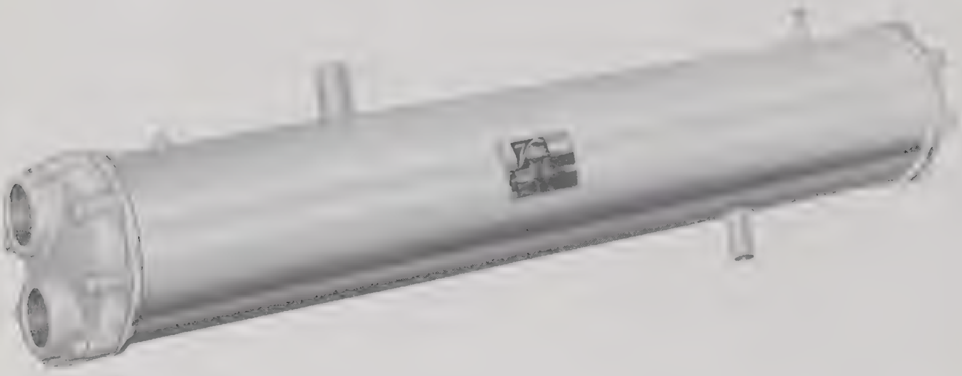


Courtesy Bohn Heat Transfer Division

FIG. 1.3. VIEW OF AN AIR COOLED CONDENSER WITH MULTIPLE FANS. CYCLING OF FANS IS SOMETIMES USED FOR COLD WEATHER CONTROL OF CONDENSING TEMPERATURE.

Temperature

Temperature indicates the level of heat, or how hot or cold an object may be. It does not indicate any specific amount of heat but is only a



Courtesy Vilter Manufacturing Company

FIG. 1.4. EXTERIOR VIEW OF WATER COOLED REFRIGERANT CONDENSER. SHELL IS FILLED WITH SMALL TUBES AND CONDENSING WATER IS DIRECTED THROUGH TUBES IN VARIOUS NUMBERS OF PASSES BY WEBBING IN HEADS. REFRIGERANT IS CONDENSED WITHIN THE SHELL AND DRAINED OUT AT BOTTOM.

measure of the heat intensity. Temperatures are measured by thermometers of one type or another. The most commonly used scales are the Fahrenheit, which was devised by a man named Fahrenheit, and the Centigrade scale which was devised by a man named Celsius. In the International System, the Centigrade scale is officially called the Celsius scale.

The Fahrenheit scale is based on water freezing at 32°F and boiling at 212°F, all at atmospheric pressure. The spread is 180 degrees between the freezing and boiling points of water. The Celsius scale is based on water freezing at 0°C and boiling at 100°C. The spread of temperature on the Celsius scale is based on 100 degrees between the freezing and boiling of water. The Celsius degree is of greater magnitude than the Fahrenheit by a ratio of 180 to 100 or 9/5. Temperatures may be freely changed from one scale to the other by the following formulas.

$$\text{Celsius} = 5/9 \times (\text{Fahrenheit degrees} - 32)$$
$$\text{Fahrenheit} = (9/5 \times \text{Celsius degrees}) + 32$$

Tables are also available giving conversions from Fahrenheit to Celsius and Celsius to Fahrenheit. One will be found in the appendix of this volume.

Specific Heat

Specific heat is a useful tool in determining cooling or heating requirements of substances other than water. It is assumed, for all practical purposes, that water has a specific heat of unity, or 1. In essence, specific heat is the ratio of the quantity of heat to raise or lower the temperature of a given weight of a substance compared to the amount of heat required to raise or lower the same weight of water through the same temperature range as the substance, usually one degree. The specific heat is usually expressed as a decimal: i.e. 0.75, 0.80 etc.

Heat Units

In the United States, the common heat quantity has been the British Thermal Unit and is usually abbreviated as Btu. By definition, one Btu is the amount of heat required to raise, or lower, the temperature of 1 pound of water 1 degree Fahrenheit.

In the metric system, weights are in kilograms (2.2 lbs) and heat units are in calories. The heat unit is the kilogram-calorie. The common refrigeration quantity in the English system is the ton of refrigeration. Since ice was one of the first substances used for refrigeration, it was only natural to equate refrigeration with ice melting effect. The ton of refrigeration is defined as the amount of heat required to melt one ton (2000 lbs) of ice at 32°F (0°C) in 24 hours. To melt one pound of ice at 32°F (0°C) requires 144 Btu. Therefore, 1 ton of refrigeration may be defined as 2000 lbs × 144 Btu/lb = 288,000 Btu per 24 hours; or 12,000 Btu per hour, or 200 Btu per minute. This is a rate of cooling. The term "ton of refrigeration" is applicable to cooling at any temperature and is, of course, not confined to ice melting. The ice melting equivalent serves only to define a quantity of heat.

Heat Transfer

All refrigeration involves heat transfer in one form or another and is normally concerned with the removal of heat, or flow of heat out of an object or area to lower the temperature of the object or area. Heat always flows from a warm to a cold body. It cannot flow uphill. Heat may be transferred in three ways and is usually transferred by a combination of the three ways. The three methods of transfer are conduction, convection and radiation.

Heat transfer by conduction is the transfer of heat through a substance, or touching substances. It may be illustrated by the heating of one end of a metal rod. Heat will flow by conduction to the other end of the rod and warm it. Heat is also transferred from the outside of the tube or vessel by conduction through the metal tube wall.

Heat transfer by convection in a cold room means cooling by air currents transferring heat from warm walls or products to the surface of the refrigerated cooling coil. The heat is removed from the air by conduction through the coil metal to the refrigerant within the coil and the cooled air circulates back through the room, usually by forced fan circulation, where it picks up more heat for cooling by the refrigerated coil.

Heat transfer by radiation is usually more active in heating than cooling. The sun warms the earth by the radiation of heat. A heated ceiling will heat objects below by radiation even though the surrounding air may be quite cool. A heated floor will radiate heat and will also set up air currents which transfer heat by convection. An example of radiation heat is that of the sun melting an ice layer on concrete even though the air temperature is well below freezing. A limited amount of cooling may be done in a cold room by radiation from walls and products to the colder refrigerated coil. The major portion of cooling however, is normally accomplished by convection to the coil and conduction of heat through the coil to the refrigerant.

Absolute Pressure

Two pressure nomenclatures are used more frequently in refrigeration calculations. These are gauge pressure (psig) and absolute pressure (psia) expressed in pounds per sq in. In the metric system, pressures can be expressed in kilograms per square centimeter (kg/cm^2). Gauge pressure is the pressure indicated on a standard pressure gauge. This indicates the pressure inside of an enclosed vessel compared to the atmospheric pressure outside the vessel. There is a second ingredient in the pressure picture however; and that is the pressure of the atmosphere from the stratosphere to the surface of the earth. This pressure varies somewhat depending on atmospheric conditions and is the pressure indicated by a barometer. Most people are familiar with the barometer from its use in weather predictions. This pressure is usually indicated in inches of mercury pressure and will average about 30". This means that the pressure of the atmosphere will push a column of mercury to a height of 30". This is equivalent to approximately 14.7 psi (1.03 kg/cm^2). To obtain absolute pressure, the weight of the atmosphere must be added to the gauge pressure. For most computations, the Figure of 14.7 psi (1.03 kg/cm^2) as atmospheric pressure is sufficiently accurate. The absolute pressure is important in a number of computations such as compression ratios. Pressures below 0 psig are often said to be in a vacuum. This is not true. These pressures are less than atmospheric and are frequently referred to a vacuum in this sense but zero pressure absolute is the theoretical lowest point of pressure that can be achieved. All pressures are positive with reference to absolute pressure. Pressures below atmospheric are frequently expressed in inches of mercury. One inch of mercury is equal to slightly less than 0.5 lbs per sq in pressure (.035 kg/cm^2).

HEAT ENERGY

Sensible Heat

Sensible heat is the heat energy required to raise the temperature of a substance, or the extraction of heat to cool a substance. It is the heat required to raise, or lower, the temperature of a substance whether it be in the form of a liquid, solid or vapor; but not the heat to change its state as from a liquid to a solid, liquid to a vapor or the reverse.

Latent Heat

Latent heat is the heat required to be applied, or extracted from a substance to effect a change of state such as a liquid to a solid, solid to liquid, liquid to vapor or vapor to liquid. The temperature of the substance does not change during this period as long as pressures remain constant. The latent heat is usually a relatively large quantity. As an example; 1 Btu will change the temperature of a pound of ice by 2°F. To melt a pound of ice or freeze a pound of water requires 144 Btu (latent heat) with no change in temperature. 180 Btu of sensible heat will raise the temperature of a pound of water from 32°F to 212°F, or the boiling point. It then requires 970 Btu to boil the pound of water into steam at 212°F. Finally, it requires somewhat less than 0.5 Btu to raise the temperature of the pound of steam 1°F. Conversely, the same amount of heat must be extracted to reverse the process. When a liquid is changed to a solid, the heat required is known as the latent heat of fusion. When a liquid is changed to a vapor, the heat required is known as the latent heat of vaporization.

COMPRESSION CYCLE

Use of the Compression Cycle

There are two types of refrigeration systems most commonly in use. These are the absorption system and the compression system. In warehouse operations, the compression system is by far the most commonly used. This cycle will be explained in some detail since it applied to virtually all cold storage refrigeration systems.

Compression Refrigeration Cycle

Fig. 1.5 shows the basic components of a compression refrigeration cycle. All refrigeration compression systems are composed essentially of these basic items in one form or another. Other items are often added for

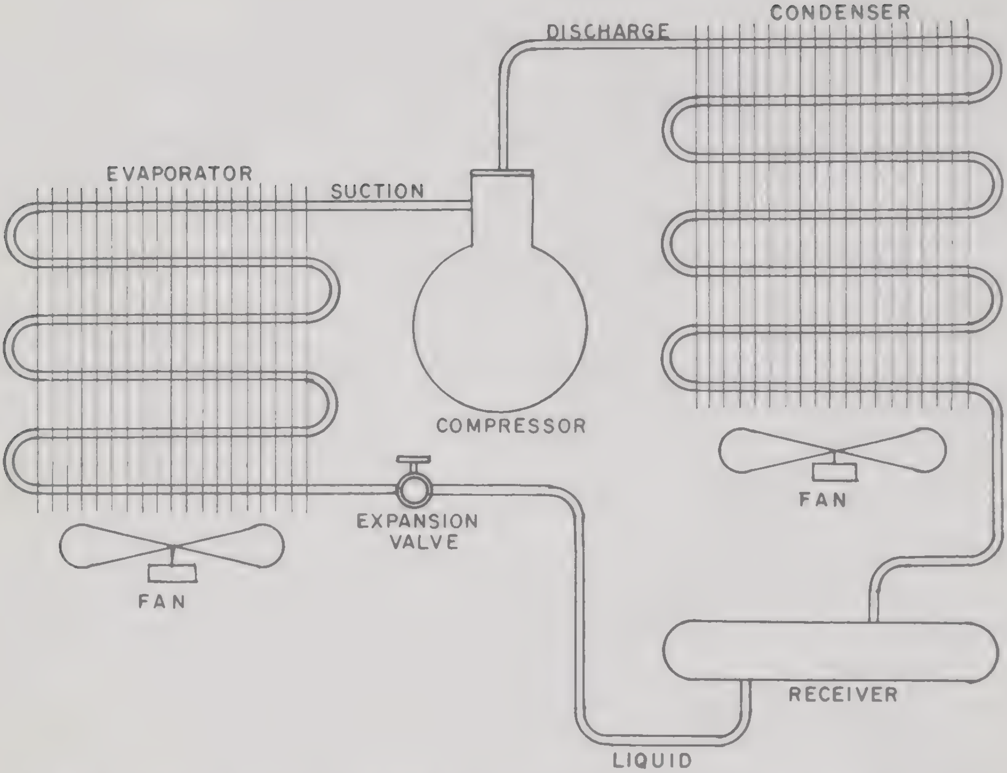


FIG. 1.5. BASIC ELEMENTS OF THE COMPRESSION REFRIGERATION CYCLE.

a more sophisticated system but, from the simplest to the most complicated system, the elements shown in the diagram will always be present.

Fig. 1.6 shows an evaporator similar to the one shown in Fig. 1.5. In this instance, the evaporator is indicated as a pipe coil with fins on the outside surface to increase the amount of surface in contact with the air. Room air is blown over the outside of the coil by the action of the fan. The boiling refrigerant inside the tube absorbs heat from the air passing over the tube surface, cooling the air. The evaporator can take many forms but the cooling action is essentially the same; a relatively cold boiling refrigerant, enclosed, absorbing heat from a substance or fluid that is relatively warm passing over the outside surfaces of the evaporator. In Fig. 1.6, the evaporator is shown connected directly to a container of refrigerant with the flow of refrigerant to the coil controlled by valve V_1. Valve V_2 on the outlet of the evaporator is adjusted to keep the system at the desired operating pressure. Valve V_1 admits a sufficient quantity of liquid refrigerant so that it will be completely evaporated just before reaching the

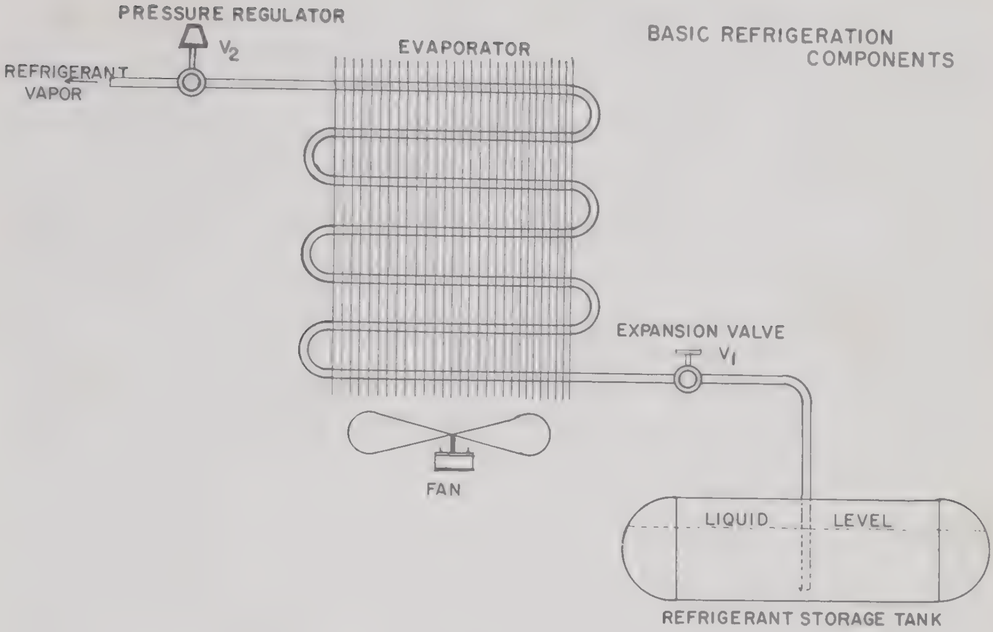


FIG. 1.6. ELEMENTAL REFRIGERATION SYSTEM.

outlet valve V_2. This is an illustration of the actual refrigeration portion of the compression cycle, or system. Since refrigerants are expensive, they cannot be discarded after a single use as shown in Fig. 1.6 but must be recovered and used over and over again. The system shown in Fig. 1.5 is a complete compression cycle. All of the components shown, except the evaporator and expansion valve, are for refrigerant recovery and storage.

Referring to Fig. 1.5 showing the compression cycle, the refrigerant vapor leaving the evaporator is drawn into the suction connection of the compressor. The compressor should be sized to draw the refrigerant vapor from the evaporator, or evaporators, at a sufficient rate to balance the refrigerant liquid being admitted to the evaporator and evaporated and to maintain the proper evaporation (boiling) pressure to produce the temperature desired. The refrigerant vapor is, at this point, said to be at suction pressure since it is at the pressure imposed on it by the suction of the compressor. Another term used for this pressure is "back" pressure, presumedly because it is the pressure back of, or before, the compression.

The compressor elevates the refrigerant vapor pressure to some point higher than the suction pressure. This pressure is usually called discharge or head pressure; both referring to the completion of the compression by the compressor. At this pressure, the temperature corresponding to it will be at a higher point than the temperature of the condensing medium which may be either air or water. The refrigerant vapor enters the interior of the condenser and the condensing medium flows over the exterior surfaces. Since heat flows from a warm to a cold body, the heat will flow from the high pressure, hotter, refrigerant to the cooler condensing medium, warming it and the refrigerant vapor will condense into a liquid. As stated in the definitions, the removal of heat from a refrigerant vapor at constant pressure will change the vapor to a liquid. The liquid refrigerant flows into the receiver. The receiver is no more than a storage vessel to hold excess refrigerant until it is needed by the system. This completes the refrigeration cycle and the refrigerant is now ready to start its journey all over again to produce more refrigeration. This is a continuous process as long as refrigeration is needed.

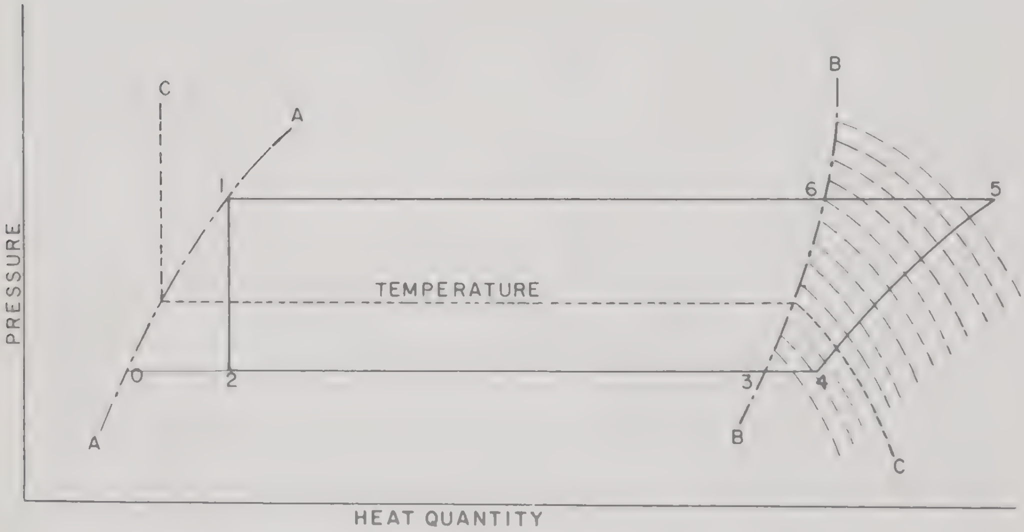


FIG. 1.7. SIMPLE REFRIGERATION CYCLE. BASIC DIAGRAM.

Fig. 1.7 offers a visual chart of the refrigeration compression cycle where pressures are plotted against heat quantities. The cycle shown is typical. Different refrigerants will vary the form of this diagram somewhat but the cycle is similar for all refrigerants. In Fig. 1.7, line A-A represents the points where all of the refrigerant is liquid and at a temperature corresponding to its pressure. Line B-B represents the points at which all of the liquid has been evaporated into a vapor, still at the same temperature. This is called the saturated refrigerant line, meaning the refrigerant is all in a vapor form with no increase in temperature. A slight increase in heat will cause the vapor temperature to rise (superheat). A slight decrease in heat will start condensation but will not lower the temperature of the vapor if the pressure is constant. Between A-A and B-B, the temperature remains constant with constant pressure on the refrigerant. To the left or right of these curves, the temperature of the refrigerant may be varied although the pressure does not change. Adding heat beyond line B-B will cause superheating and raise the temperature of the vapor. To the left of line A-A, extraction of heat will lower the temperature of the liquid refrigerant. This is called subcooling.

A typical refrigerating cycle starts at point 1 in Fig. 1.7. At this point the refrigerant is all liquid and at high, or condensing pressure and temperature. It is at this point that the refrigerant enters the expansion valve which abruptly reduces the pressure from point 1 to point 2. In dropping the pressure on the liquid, it will be cooled to the evaporator temperature corresponding to the pressure at point 2. The quantity of heat represented from point 0 to 2 has now been used to chill the liquid down to the evaporator temperature. This will result in a mixture of gas and liquid at point 2 since the cooling effect was obtained by vaporizing part of the liquid metered into the evaporator by the expansion valve. The gas vaporized at this point is often referred to as "flash gas". As heat from the surrounding medium, room air or other cooling load, flows into the cold refrigerant in the evaporator, the refrigerant continues to vaporize (boil) and absorb heat. This quantity of heat is represented on the diagram from point 2 to point 3. This is the remainder of the latent heat of vaporization and is the largest single quantity contributing to the cooling. After the refrigerant is all evaporated, some further heat may be added to the vapor before it enters the compressor. This is superheat and is the quantity of heat between point 3 and 4. This quantity is somewhat limited. The addition of heat at this point also raises the temperature. The volume of gas per pound of refrigerant is also increased by the addition of superheat. During the superheat period, the pressure remains essentially constant. At point 4, the vapor enters the compressor. After the vapor enters the compressor, it is compressed and the pressure elevated to point 5 of the diagram. The temperature also rises rather rapidly as the work of the compressor is converted to heat and this superheats the compressed vapor. The refrigerant vapor is now at head, or condensing pressure where it enters the condenser at point 5. The condensing medium, at a temperature lower than the refrigerant saturated temperature corresponding to its pressure, causes heat to flow from the refrigerant vapor to the condensing medium. The superheat is first removed from the vapor which brings it to point 6. The vapor is then condensed to a liquid by removing the quantity of heat represented between point 6 and point 1. At this point, the refrigerant is again a liquid and the refrigerant cycle is ready to start over again.

It should be noted that considerably more heat must be removed from the refrigerant vapor to condense it than the refrigerant removes in its trip through the evaporator. This is true because the work of the compressor to compress the vapor from the evaporator is turned in to heat which is additive as superheat to the refrigerant. This heat must be removed by the condenser plus the heat removed in the evaporator.

It should also be noted that the heat energy used to compress the refrigerant vapor is less than the energy equivalent obtained in the evaporator. This does not mean that the system is producing something for nothing or operating at better than 100% efficiency. All that a compression refrigeration cycle does is to remove heat at a low level; then pump that heat to a higher level where it can be disposed of, or carried away, by some medium that is abundant such as air or water. It should also be noted that the horsepower, when translated into heat units, is represented by the heat quantity between points 4 and 5 of the diagram in Fig. 1.7. As head pressures are kept low, less horsepower will be needed to compress the refrigerant vapor since it will not have to be elevated as high in pressure. This will result in a more efficient system with a consequent saving in power consumed. Low head pressures are obtained by generous condensing surfaces and as low a temperature as possible for the condensing medium. Diagrams similar to the one shown in Fig. 1.7 are available for most refrigerants giving specific information about the particular refrigerant and are very useful in analysing plant performance.

Two Stage Refrigeration Cycle

Fig. 1.8 illustrates an adoption of the compression system that is often used for freezer storage operations and particularly with ammonia refrigerating systems. This system is the two stage, or booster, system in which the refrigerant gas is compressed in two stages instead of a single stage. The low stage compressor is normally called a booster compressor. This makes for a more efficient use of compressors with the high stage compressor being a standard heavy duty type. The low stage, or booster, compressor may be somewhat lighter construction since it does not have exceptionally high pressure imposed on it. By compressing the refrigerant vapor in two stages, the compression ratio (ratio of absolute discharge pressure to absolute inlet, or suction, pressure) is lowered with the result of more efficient compressor operation. Also, by using intercooling, the efficiency is further enhanced. When properly designed, the two stage system will show a horsepower advantage over a single stage system for low temperature use.

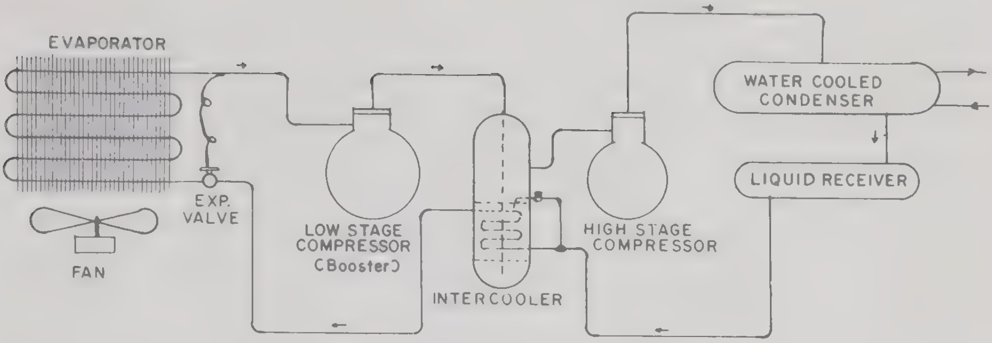


FIG. 1.8. DIAGRAM OF TWO STAGE REFRIGERATION COMPRESSION SYSTEM.

In the two stage system illustrated schematically in fig. 1.8, liquid refrigerant from the receiver flows to an intercooler instead of directly to the evaporator. In the intercooler, part of the liquid refrigerant enters the intercooler where it cools itself down to the temperature corresponding to the intermediate, or middle pressure. The balance of the liquid refrigerant flows through a pipe coil submerged in the pool of intercooler refrigerant where it is also cooled. The cooled liquid is then piped to the evaporator and the pressure reduced at the evaporator inlet by an expansion valve in the same manner as in the single stage compression system. It should be noted that the liquid refrigerant entering the evaporator has already been partially cooled in the intercooler so that not as much cooling is now required in the evaporator to cool the entering liquid to evaporator temperature as is needed in a single stage system. This results in less flash gas and more efficient use of the evaporator surface which is desirable. The refrigerant vapor from the evaporator enters into the low stage compressor suction and is compressed to the intermediate pressure instead of all the way to the condensing pressure. The refrigerant gas discharged from the booster is heated by the work of compression. It flows into the intercooler and is bubbled through the pool of liquid refrigerant in the intercooler which chills it near the saturated temperature of the intermediate pressure. The chilled vapor is then drawn in the suction of the high stage compressor where it is compressed to condensing pressure. The high pressure refrigerant is then condensed and collected in a liquid receiver as in the single stage system.

Booster, or two stage, systems are used normally for storage room temperatures of about 0°F (−18°C) or lower. An optimum intermediate pressure to produce maximum efficiency can be calculated. Most frequently, however, the optimum may not be used when there are cooler loads requiring refrigerant suction pressures near the optimum pressure.

By combining the intermediate pressure load from the booster compressor with other cooler refrigeration loads, excess machinery is not required, piping is simplified and very little efficiency is sacrificed.

There are many variations of two stage systems. Most of them operate with good efficiency. The diagram shown in Fig. 1.8 is not meant to express a particular preference but merely to illustrate the operation of such a system. A good two stage system, properly designed and installed, can show power savings in a cold storage operation and should always be considered in the design phase of any sizable installation.

Coefficient of Performance

The coefficient of performance of a compression cycle of refrigeration- is one method of measuring the efficiency of operation. The coefficient of performance is the ratio of the energy (heat absorbed) in the evaporator to the energy input to the sytem. The energy equivalents must be changed to a common form, such as Btu, before the ratio can be expressed. This ratio will normally be considerably greater than unity since, as explained before, the energy input is a means of changing heat levels and is not an expenditure equivalent to the work accomplished by the cooling.

Compression Ratio

The compression ratio of a compression system is important to know since compressors tend to become inefficient as the compression ratio increases. Compression ratio actually refers to the volume of gas pumped by a compressor at discharge pressure with respect to the gas entering the compressor at the suction pressure. Since gas volume varies inversely with pressure, the compression ratio can be related to pressures which can rather easily be obtained. The compression ratio is the ratio of high, or head, pressure to the low, or suction, pressure. These pressures must be expressed as absolute pressures rather than gauge pressures. For practical purposes, absolute pressure may be expressed as gauge pressure plus 14.7 psi (1.03 kg/cm^2). A ratio of 6 to 1 is normally not exceeded in a reciprocating (piston type) compressor.

Heat Pump

By reversing the refrigerant flow and using the normal condenser as an evaporator and the normal evaporator as a condenser, heating the inside air may be accomplished. Condensing of the refrigerant vapor will warm the air used for condensing and this warmed air can be used to warm an enclosure to comfortable conditions. This type of system will normally produce considerably more heat for comfort heating than straight electrical resistance heating for the same expenditure of energy since the heat pump is a system of changing heat levels rather than straight conversion of electrical energy to heat. One disadvantage of the heat pump is that some auxiliary heating is usually required, particularly in cold climates, since as the outside temperature becomes lower, the efficiency of the heat pump is lowered so that the least amount of heat is available when the most amount of heat is needed. This is true when outside air is used as a source of heat for the heat pump. Where a heat sink is available such as constant temperature water or air or underground source at a temperature higher than the low ambient temperature available during cold weather, the heat pump can perform with better efficiency. In areas where both heating and cooling must be done with electrical energy, the heat pump will usually show definite savings over straight electrical resistance heating.

The largest use of the heat pump is probably for air conditioning although there are numerous industrial applications. Industrial applications include process heating and cooling, reheating and many diversified uses which use all or part of the heat pump principle. Heat pumps have not been used generally in cold storage except for some limited uses for very special storage conditions. This very simplified explanation of the heat pump is included only for information. It is not intended as an argument either for or against the pump.

REFRIGERATED SPACE

Various warehouse storage areas can be designed for different applications. There is also value in the "convertible" room which can be used for either cooler or freezer applications. So many different factors apply to the design of a cold storage facility that it is almost impossible to arrive at a set load figure per square foot of floor area or cubic foot of volume that will apply equally to all spaces.

There are some rules of thumb that can be used if they are used only as a guide to know if a load calculation is within reason or not. A rule of thumb for freezer rooms in the area of 10,000 sq ft with ceilings approximately 20 ft high is 30 to 40 tons refrigeration. This is based on good insulation and normal storage room operation with no appreciable freezing of merchandise within the room. This figure will allow a nominal amount of loading, such as frozen merchandise that may need cooling a few degrees to storage temperature. Small quantities of products may also be slow frozen. As room sizes increase, the unit refrigeration requirements may reduce slightly and rooms smaller may require more refrigeration per size unit. In the normal course of freezer room life with expected use increases and deterioration of the room structure, it is difficult to put too much refrigeration in a room and many designers do not take all of these factors into consideration as fully as they should. The refrigeration capacity for a cold storage room is a combination of theoretical design plus experience and judgment and unless all of these factors are considered, an inferior design may result.

Cooler rooms will run slightly less tonnage than freezers and considerably less horsepower per ton since they normally operate at higher refrigerant temperatures than freezers.

It is difficult to give any valid rules for large rooms and complete cold storage facilities since each room and each facility needs to be evaluated on its own merits and the use for which it was intended. In the face of energy shortages and high energy costs, the plant of the future will certainly be designed for less power consumption than the present plants. This can be accomplished by better and more room insulation and by more careful selection of refrigeration components and design parameters.

TABLE 1.1. COMPRESSION RATIOS OF COLD STORAGE REFRIGERANTS (STANDARD TON CONDITIONS)

	Gauge Pressure, psi		
Refrigerant	At 86°F (30°C) Discharge	At 5°F (−15°C) Suction	Compression Ratio
R. 502	175.1	35.99	3.75
R. 22	159.8	28.33	4.05
R. 717 (Ammonia)	154.5	19.57	4.94
R. 500	112.9	16.40	4.12
R. 12	93.2	11.81	4.07

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2

Refrigerants and Refrigerant Characteristics

In the preservation of foods, ice probably was the first widely used cold substance. Ice was a natural occurrence in colder climates and its properties have been known and used for hundreds of years for various cooling tasks including air conditioning. Natural ice, in the early years of this country, was harvested in large quantities from lakes and rivers during the cold winter months and stored in sawdust insulated enclosures for use during warm weather. It was not until the middle and latter part of the nineteenth century that serious efforts were made to use substances other than ice as a possible means of making things cold. Many substances were demonstrated to have refrigerant properties and progress was made experimentally on a number of methods of refrigeration. Two systems, the absorption and compression, emerged as the most widely used.

Ammonia gradually came into general use as the refrigerant used in both the absorption and compression systems of refrigeration. Many absorption ice plants were constructed near the turn of the century utilizing the condensed steam as distilled water to make clear ice. With the development of the reciprocating compressor for refrigeration, the absorption plant for commercial purposes more or less phased itself out of existence since the compression system proved cheaper to build and was simpler to operate. Steam engines were most frequently used as drivers since the condensed steam was needed for the manufacture of clear ice. As raw water ice plants were developed, steam engines as drivers were replaced by electric motors and internal combustion engines.

HISTORICAL

Ammonia, as a refrigerant, was used almost exclusively in ice plants throughout the first third of the twentieth century. Since most cold storage operation, at that time, was in connection with ice plants; ammonia became almost the universal refrigerant. Most refrigeration equipment manufacturers concentrated almost entirely on the production of ammonia equipment. Strangely enough, overall efficiencies of compressors plus plant design reached a high point during this period which may not have been exceeded in industrial installations since that time. The price of manufactured ice was very competitive and manufacturing costs were watched very carefully. Low operating costs (high efficiencies) were required in any new plant to stay competitive with the ice market.

Prior to the 1930s, the small meat market, grocery and corner drugstore fountain used small ammonia refrigeration systems or ice bunkers to maintain cold space for food preservation. The small ammonia plants, at best, were somewhat cumbersome for this type service and required cooling towers or city water connections for the water cooled condensers. Rather frequent maintenance was also required. The use of ice also required considerable labor and depended on the reliability of an ice supply.

At about this time, the small light weight compressor was developed for the small market. It used refrigerants other than ammonia of the so-called "low pressure" class and also utilized the air cooled condenser. Among the first of these refrigerants were sulphur dioxide and methyl chloride which, although excellent refrigerants, were hazardous when used in confined spaces. Although they allowed small compressors of light weight materials to be used with air cooled condensers, they did not actually reduce the hazards of refrigerants. Methyl chloride is flammable and also toxic. It has a relatively pleasing odor and can be tolerated with little or no initial discomfort; thus, dangerous quantities could be absorbed into the body without any unpleasantness or initial discomfort. Sulphur dioxide, if anything, is more odorous than ammonia and can also be considered toxic. Numerous accidents prompted the research and development of safer refrigerants and in the early 1930s, the halocarbon refrigerants began to come into use. The first one to be used in quantity was refrigerant R-12. The E. I. DuPont Company was primarily responsible for the development of the halocarbons and supplied them under the trade name of "Freon". A number of years later, when other chemical companies started to manufacture these refrigerants, much confusion arose as to nomenclature. DuPont then allowed the use of its numbering system of refrigerants to be used by the entire industry to indicate identical refrigerants regardless of where manufactured. This numbering system is still in use and has avoided a tremendous amount of confusion.

The halocarbons were much safer than the earlier refrigerants used. They were also practically odorless which prevented panic hazard from leaks and, for the most part, were not toxic. They were a tremendous spur to the development of refrigeration equipment for a great variety of uses. The halocarbons have been used in almost all sizes of refrigeration equipment. Ammonia has also remained in general use, confined mostly to industrial operations such as cold storage, ice making, process refrigeration, etc. In many instances, ammonia is the preferred refrigerant in these applications. The halocarbons, except in some exotic fields, have pretty well replaced other refrigerants except ammonia.

Air conditioning systems were given a tremendous boost with the use of the halocarbon refrigerants. The safety features made them a natural choice to enlarge this field. Great impetus was given to the design of equipment for air conditioning applications and a whole new industry was born. Curiously enough, although both air conditioning and refrigeration applications employ refrigeration equipment such as compressors, evaporators and allied equipment; there sometimes exists a considerable difference in the type of equipment utilized for the two applications. There is no hard and fast line between the two and there are frequent overlaps; but often there are definite differences in design parameters and selection of equipment. The industrial refrigeration equipment is most often of a heavy duty nature with emphasis placed on long life and good operating efficiencies. Air conditioning as well as some commercial refrigeration has frequently been designed with more emphasis on first cost than on operating and maintenance costs. It could be anticipated that with energy shortages and high power costs, that in the future, all types of refrigeration systems will be designed with high efficiencies and low operating costs as the prime consideration.

PRIMARY AND SECONDARY REFRIGERANTS

In the compression system of refrigeration described in Chapter 1, the refrigerant is known as a primary refrigerant because it is this fluid that produces the refrigeration in a cooling coil. Generally, a prime refrigerant can be described as a refrigerant that produces a cooling effect by the boiling, or vaporizing, of the refrigerant in a coil (evaporator) of some type placed directly in the area being cooled and utilizing the latent heat of vaporization of the refrigerant in the process.

In some refrigeration systems, it is not desirable to have the primary refrigerant in the area being cooled. This can be for a variety of reasons such as possible contamination of stored product from a refrigerant leak, possible refrigerant panic hazard or extreme length of refrigerant lines of large size. Long suction lines, with some refrigerants will produce an intolerable pressure drop. When a primary refrigerant is not desirable, it is common practice to use the primary refrigerant to chill a fluid such as calcium chloride brine (a mixture of calcium chloride crystals and water) and circulate this chilled fluid through a coil in the area being cooled. The brine acts as a secondary refrigerant. Room air blowing over the coil is cooled as the brine circulating within the coil is warmed. The cooled air is then circulated to the room and the brine returns to the brine chiller where it is again chilled by the primary refrigerant. As can be seen, the brine, or secondary refrigerant absorbs heat by sensible heating only: warming the brine rather than by vaporization, or boiling. Chilled water in an air conditioning system acts as a secondary refrigerant. In low temperature applications, fluids normally used as primary refrigerants are sometimes used as brines or secondary refrigerants by circulating them at temperatures well below their vaporization points; thus using them to absorb heat by temperature rise only and not by vaporization. These fluids are cooled by the primary refrigerant in the same manner as is done in any brine system.

AZEOTROPES

Most primary refrigerants are basic fluids with definite characteristics and temperature-pressure relations. Occasionally two refrigerants, or fluids, may be combined in certain proportions to produce a third fluid with characteristics totally different from either of the basic ingredients. R-500 and R-502 refrigerants are azeotropes of this nature. They are stable throughout their refrigeration use range and do not separate out into their basic components under any conditions at which they are normally used. They are treated the same as any other refrigerant in calculations.

CHARACTERISTICS OF REFRIGERANTS

Boiling and Condensing Temperatures and Pressures

In a compression system of refrigeration, the evaporating and condensing temperatures of the refrigerant will determine the pressures at which the system will operate. In most instances, it is desirable to select a refrigerant that will operate at pressures above atmosphere at all times since it is difficult to detect inward system leaks. An inward leak will introduce air into the refrigerant circuit which will not mix with the refrigerant. The condensing pressure of the system with air or other non-condensable gases then becomes the pressure corresponding to the temperature of condensing plus the pressure imposed by the non-condensable gases which are additive in proportion to the amount present. The higher pressure requires more energy to compress the refrigerant gas and is undesirable. Non-condensables should always be kept out of a system. When present, they may be extracted from the system by means of a device called a purger and which is usually automatic in operation. Some low temperature systems may require evaporating pressures below atmosphere and extra care should be taken to achieve a tight system to prevent inward leaks.

Freezing, Critical and Discharge Temperatures

A good workable refrigerant should have a freezing point well below the temperature at which it will be used to avoid any problems with the solidification of the refrigerant. All commonly used refrigerants have freezing points well below their operating range.

The critical temperature is that temperature above which it is impossible to condense the vapor (gas) by the application of pressure. Obviously, this temperature should be well above any temperature that might be encountered in the refrigeration cycle.

The thermodynamic properties of the refrigerant should be such that when the refrigerant vapor is compressed to condensing pressure, the temperature of the vapor is not high enough to cause possible chemical breakdown of the refrigerant or to cause deterioration of the oil so that poor lubrication and undesirable oil properties will result.

Latent Heat of Vaporization

Refrigerants used in the compression cycle pass through a liquid and vapor state. The latent heat of vaporization is the amount of heat absorbed by the refrigerant in changing from a liquid to a vapor. This is the principal source of heat removal by the refrigerant and a good refrigerant should have a high latent heat capability.

Compression Ratio

The ratio of the suction to the discharge pressure is important in the design of a compressor and also on the horsepower required by the compression system. A low compression ratio usually indicates efficient compressor operation. Compression ratios of 6 to 1 can be considered in the low range. High compression ratios can result in decreased compressor efficiency. Excessive discharge gas temperatures with harmful results can also occur where high compression ratios are present. When higher compression ratios are necessary, as in low temperature work, it is usually advisable to use a two stage system. Compression ratio is the ratio of the absolute discharge pressure to the absolute suction pressure.

Chemical Characteristics

The chemical characteristics of refrigerants are important from the standpoint of good performance as well as fire hazard, safety, odor and other considerations. Table 2.1 indicates the chemical nomenclature of various refrigerants commonly used in various refrigeration systems.

Toxicity

The toxicity of refrigerants has been rated by the Fire Underwriters Laboratories. The rating is based on the toxic effect on humans over a specified period. Table 2.1 gives comparative ratings of some of the common refrigerants. It should be realized that although some refrigerants are more toxic than others, any refrigerant is dangerous in confined quarters since it can replace the normal breathing air and cause serious problems from lack of oxygen. Adequate ventilation of refrigeration machine rooms is important regardless of the refrigerant used. Dangerous conditions within cold storage areas are somewhat more remote but can build up. With ammonia, the odor of a very small amount will usually cause evacuation and repair at an early date. Odorless gases can be somewhat more insidious and storage rooms should be checked for leaks on a regular basis. Checking for halocarbon leaks is relatively simple. A halide leak detector, which is a flame burning around a copper target, can be used. The flame will be of a bluish color in an uncontaminated atmosphere but will tend to turn yellow or green in the presence of a halocarbon. Reliable electronic devices are also available for detecting the presence of a halocarbon in very minute quantities.

Flammability – Explosion Hazard

Flammability and explosion hazards cause the rejection of some refrigerants that may have excellent thermodynamic properties for refrigeration. Propane is an example of this type of refrigerant. With the possibility of a leak that could produce concentrations of gas that could easily ignite and explode, gases with high explosive hazard cannot be used as refrigerants except under unusual circumstances of refrigeration applications where the hazard is understood and compensated for. For the most part, the halocarbon refrigerants are non flammable and do not present an explosion hazard per se. Oil carried along with the refrigerant can be ignited. Also, in the presence of open flame, some of the halocarbons can produce irritants and toxic gases. This presents no particular problem in their use but should be kept in mind. Ammonia will burn within rather narrow limits of concentration and will also produce an

TABLE 2.1. CHARACTERISTICS OF REFRIGERANTS COMMONLY USED IN COLD STORAGE WAREHOUSE REFRIGERATION SYSTEMS *

Refrigerant (R)		717 Ammonia	11 Trichlorofluoromethane	12 Dichlorodifluoromethane	22 Chlorodifluoromethane	500 12/152a Azeotrope	502 22/115 Azeotrope
Chemical formula		NH_3	CCl_3F	CCl_2F_2	$CHClF_2$	CCl_2F_2/CH_3CHF_2	$CHClF_2/CClF_2CF_3$
Boiling Point @ 1 atm.	°F	−28.0	74.8	−21.6	−41.4	−28.3	−49.8
	°C	−33.3	23.8	−29.8	−40.8	−33.5	−45.4
Freezing Point	°F	−108	−168	−252	−256	−254	—
	°C	−77.8	−111.1	−157.8	−160.0	−158.9	—
Critical Temp.	°F	271	388	234	205	221	180
	°C	132.8	197.8	112.2	96.0	105.0	82.2
Critical Pressure	psia	1657	639	597	722	642	591
	kg/cm^2a	116.5	44.9	42.0	50.8	45.1	41.5
Molecular wgt.		17	137.4	120.9	86.5	99.3	111.6
Underwriters safety rating		2	5	6	5a	5a	5a

* Numbers rounded for easy comparison

explosion although apparently not of great magnitude. Oil in ammonia lines can produce a fire hazard as in other refrigerant lines. There have been a number of explosions and fires in refrigerated installations blamed on the refrigerants used in that particular plant. Upon careful examination, a great many of these have been traced to some other cause rather than refrigerant explosion or burning.

Refrigerants work under pressure. Some refrigerants operate under higher pressures than others but some pressure is involved in any compression refrigeration cycle. All refrigerants are not compatible with all metals. Pressure vessels should be designed to withstand the pressures under which they will operate plus a reasonable factor of safety. Metals should be compatible with the refrigerant used. All pressure vessels should be equipped with appropriate pressure relief devices which will relieve pressure before the danger point is reached. Existing codes should be consulted and plant equipment designed to conform. The ASHRAE safety code for mechanical refrigeration is recommended as a guide to safety requirements.

Refrigerant Odor

Odors of refrigerants may be both an asset and a liability. A definite odor of a refrigerant may be an advantage in detecting leaks but this same odor may act as a contaminant to food stuff in storage as well as being an irritant to workers in the area. Gases having little or no odor, such as some of the halocarbons, are difficult to detect but do not, as a rule, harm products in storage or prevent work in a room where there is a leak unless the leak is large enough to change the make-up of the air in the room significantly.

SPECIFIC REFRIGERANTS

Introduction

There are a great number of refrigerants known today. Only a few are in general use in the cold storage and food preservation industry. Since this volume is not intended as a general refrigeration course, discussion will be limited to those refrigerants most commonly used in commercial and cold storage installations. Other than a summary of the characteristics of other gases in the tables accompanying this chapter, no other reference to them will be made. Following are descriptions of several of the most commonly known and used refrigerants in the cold storage area.

TABLE 2.2. PROPERTIES OF REFRIGERANTS COMMONLY USED IN COLD STORAGE WAREHOUSE REFRIGERATION SYSTEMS AT STANDARD RATING CONDITIONS OF 5°F (–15°C) EVAPORATING AND 86°F (30°C) CONDENSING

Refrigerant (R)		717 Ammonia	11 Trichloro-fluoro-methane	12 Dichloro-difluoro-methane	22 Chloro-difluoro-methane	500 12/152a Azeotrope	502 22/115 Azeotrope
Suction pressure	psig	19.6	23.9*	11.8	28.2	16.4	36.0
	kg/cm²g	1.38	607.1**	.83	1.98	1.15	2.53
Condensing pressure	psig	154.5	3.5	93.3	158.2	112.9	175.1
	kg/cm²g	10.86	.25	6.56	11.12	7.94	12.31
Compression ratio		4.94	6.19	4.08	4.03	4.11	3.75
Discharge temperature	°F	210	110	101	128	105	99
	°C	98.9	43.3	38.3	53.3	40.6	37.2
Heat (enthalpy) of vapor @ 5°F (–15°C)	Btu/lb	613.3	92.57	77.81	104.96	93.42	78.24
	kcal/kg	340.75	51.43	43.23	58.32	51.90	43.47
Heat (enthalpy) of liquid @ 86°F (30°C)	Btu/lb	138.9	25.78	27.77	34.93	32.85	33.36
	kcal/kg	77.17	14.32	15.43	19.41	18.25	18.53
Net refrigeration at saturation	Btu/lb	474.4	66.79	50.04	70.03	60.57	44.88
	kcal/kg	263.58	37.11	27.80	38.91	33.65	24.94
Liquid circulated per ton (U.S.) refrigeration	lbs/min	.422	2.99	4.00	2.86	3.30	4.46
	kg/min	.191	1.36	1.81	1.30	1.50	2.02
Vapor volume @ 5°F (–15°C) saturated	cu ft/lb	8.15	12.21	1.46	1.24	1.50	.80
	m³/kg	.509	.762	.091	.077	.094	.050
Theoretical displacement per ton (U.S.) refrigeration	cfm	3.44	36.50	5.84	3.55	4.95	3.57
	m³/min	.097	1.034	.165	.101	.140	.101
Horsepower per ton (U.S.)	Hp	.989	.938	1.002	1.011	1.010	1.079
Coefficient of performance		4.76	5.03	4.71	4.66	4.67	4.37

* inches of mercury vacuum
** millimeters of mercury vacuum

Ammonia – Refrigerant 717 – NH_3

Ammonia was not the first known refrigerant but undoubtedly was the most widely used during the early years of refrigeration and is still in widespread use in commercial and industrial systems. Ammonia has very excellent refrigerant qualities. At atmospheric pressure, it vaporizes at −28°F. (−33°C). Operation in a vacuum is not normally required for cold storage temperatures. Condensing pressure at 95°F (35°C) is 181 psig (12.7 kg/cm^2). This is a reasonable pressure and causes no difficulty in compressor design. Ammonia is not miscible in oil (does not mix intimately) and there are no problems with the parallel operation of compressors with common condensers and evaporators. Two stage systems work very well with ammonia as the refrigerant. Ammonia systems can be designed for complete automatic operation and will give very reliable service. Most ammonia equipment is of heavy duty construction and hence, has a long life expectancy.

Ammonia has drawbacks when used outside the industrial field and where human occupancy is heavy. It is flammable under certain conditions. It has a very pungent odor that is unmistakable. In a sense, this odor is an operating advantage in that even small leaks will be repaired without delay. The characteristics of ammonia more or less limit its use to the industrial field of refrigeration which includes cold storage applications. It is also limited to relatively large installations since ammonia equipment is normally designed for larger installations. Flammability is limited to rather narrow limits. Ammonia should not be used directly in areas where there may be high human occupancy. Ammonia vapor can be damaging to some food products such as pecans and other highly absorbent items. Frozen foods are not too often affected unless in actual contact with liquid ammonia from a bad leak or break. Ammonia works well with secondary refrigerants where the entire ammonia plant is confined to a machine room with brine circulation to the refrigerated areas. Because it is an extremely good refrigerant, ammonia is still quite popular in the industrial field.

Dichlorodifluoromethane – Refrigerant 12 – CCl_2F_2

R-12 was one of the first halocarbon refrigerants to be used extensively. It is still used rather widely in many installations. It has a boiling point of −21.6°F (−30°C) at atmospheric pressure. Condensing pressure at 95°F (35°C) is 108.3 psig (7.6 kg/cm^2). It is useful from freezer conditions to air conditioning temperatures. For many years, R-12 was the principal halocarbon refrigerant used in the refrigeration industry. Oil separation can cause problems, if not handled properly, since oil is miscible in R-12. Line sizing is critical to the extent that upflow suction lines must be sized to maintain sufficient velocity so that oil carried to the evaporators will be returned via the suction line to the compressor. Compressors can be operated in parallel but care must be taken to see that oil equalization takes place between compressors. Line sizing and layout must also be treated carefully for parallel operation.

R-12 is odorless under normal conditions of use and presents no panic hazard, even in heavily occupied areas. In the presence of open flame, it will break down into some rather unpleasant components that can be toxic. It is non flammable and is considered a safe refrigerant. It does not contaminate stored product if a leak occurs. Oil return, as in most halocarbon systems, is dependent on proper velocities in upflow risers and in proper slope and design of the suction lines. Minimum pressure drops for economical operation require large pipe sizes and careful installation. Because of this, except in specially designed installations, plant design usually dictates that the compressors be not too far from their evaporators so that economy of suction line sizing may be achieved with minimum pressure drop. This is detrimental if a central machine room is desired with direct expansion coils throughout the cold storage areas in a large plant with remote rooms. In larger plants, unless a brine system is employed, several compressor locations may be desirable rather than a single large machine room.

Chlorodifluoromethane – Refrigerant 22 – $CHClF_2$

R-22 was primarily used in freezer applications at one time since it has a boiling point of −41.4°F (−41°C) at atmospheric pressure. This low boiling point allows R-22 to be used in low temperature applications without operating in a vacuum. Discharge temperatures are high under low temperature operation with air cooled condensers. This usually limits the use of R-22 at low suction pressures to water cooled condensers or evaporative condensers. It is used extensively in air conditioning applications with air cooled condensers. Condensing pressure at 95°F (35°C) is 181.8 psig (12.8 kg/cm^2). In air cooled condenser applications, R-22 can be operated upwards from about 25°F (−4°C) without much difficulty if condensers are sized generously, particularly at the lower temperature. Line sizing must be handled with the same care accorded R-12 to achieve good results. R-22 lines can be smaller than R-12 for the same pressure drops but are still quite large. R-22 requires less compressor displacement than R-12 for the same amount of refrigeration but the horsepower per ton is about the same.

Refrigerant 12/152a – Refrigerant 500 – CCl_2F_2/CH_3CHF_2

R-500 is an azeotrope (a mixture of R-12 and R-152a) and has a boiling point of −28.3°F (−34°C) at atmospheric pressure and a pressure of 131.2

psig (9.2 kg/cm^2) at 95°F (35°C). This particular refrigerant was developed primarily for air conditioning applications but has been used from time to time for refrigeration use. The azeotrope was developed to produce the same amount of refrigeration in a compression system operating with 50 htz power that would be produced by the same compressor operating on 60 htz power and using R-12. The same precautions need to be taken with R-500 in piping as with all halocarbons with respect to oil return and piping care. It is not too often encountered in the refrigeration field.

Refrigerant 22/115 – Refrigerant 502 – $CHClF_2/CClF_2CF_3$

R-502 was developed specifically for use in freezer applications. It has a boiling point of −49.8°F (−45°C) at atmospheric pressure and a condensing pressure of 199.7 psig (14 kg/cm^2) at 95°F (35°C). It lends itself well to freezer application. Even with air cooled condensers, the temperature of the discharge gas is not excessively high. R-502 is an azeotrope and is composed of a mixture of R-22 and R-115. The same restrictions apply to this refrigerant as to other halocarbon refrigerants. A large proportion of freezer applications, particularly small and intermediate size, with air cooled condensers are now being designed for use with R-502.

REFRIGERANTS FOR OTHER THAN INDUSTRIAL USE

Some refrigerants not normally used in cold storage applications bear familiar numbers and a review of some of these with brief comments is in order. Table 2.2 contains a listing of most of the refrigerants mentioned with pertinent data for each.

Trichlorofluoromethane Refrigerant 11 CCl_3F

The boiling point of this refrigerant is 74.9°F (24°C) at atmospheric pressure. The refrigerant works between rather narrow limits of pressure and condensing pressure at 95°F (35°C) is approximately 7 psig (.5 kg/cm^2). The principle use of this refrigerant is in water chilling for air conditioning applications and the suction pressure is always in a vacuum. Large volumes of gas must be pumped per ton of refrigeration and the larger installations are usually made with centrifugal compressors.

Methyl Chloride Refrigerant 40 CH_3Cl

Methyl Chloride has a boiling point of −11.6°F (−24°C) at atmospheric pressure. It is an excellent refrigerant but due to its flammability and toxic qualities has been almost completely replaced by other refrigerants.

Dichlorotetrafluoroethane Refrigerant 114 $CClF_2CClF_2$

R-114 boils at a temperature of 38.8°F (4°C) at atmospheric pressure. It has seen considerable use in domestic refrigerators and has also been used with centrifugal compressors and water chillers for some air conditioning applications where chilled water is used.

Propane Refrigerant 290 $CH_3CH_2CH_3$

Propane is a good refrigerant but highly flammable. Its use is confined almost exclusively to refinery and oil field refrigeration where personnel are familiar with safety precautions for this type of gas. It is not recommended for applications other than those mentioned above.

Sulphur Dioxide Refrigerant 764 SO_2

Sulphur dioxide, like methyl chloride, served in the early days of domestic and commercial refrigeration. It has a highly noxious odor and is no longer commonly used. It is of historical interest only.

Low Temperature Refrigerants – Cryogens

There is a group of refrigerants with very low boiling point temperatures which are called cryogens. These refrigerants and their characteristics are listed in table 2.3. The refrigerants include carbon dioxide, nitrogen, nitrous oxide and others. They are used in specialized very low temperature freezing applications, metalurgy, etc.

Properties of Refrigerants

Several tables are included in this chapter giving various properties of refrigerants. They are of some interest in drawing comparisons between refrigerants. It should be noted that standard conditions are taken at 5°F (−15°C) suction and 86°F (30°C) condensing temperature. This is an arbitrary figure chosen some years ago. The actual temperatures have no particular significance, but when used as a basic for comparison, give equal weight to refrigerant comparisons. It can be noted from the tables that there is little difference in the theoretical horsepower required per ton of refrigeration for the various refrigerants. The advantage of one refrigerant over another does not usually lie in the horsepower per ton required; but in other factors.

It will be noted from the tables that there is a wide variation in the amount of gas pumped per ton of refrigeration. This has an effect on the

TABLE 2.3. CHARACTERISTICS OF LOW TEMPERATURE REFRIGERANTS

Refrigerant (R)		13 Chloro-trifluoro-methane $CClF_3$	14 Tetra fluoro methane CF_4	702 Hydrogen normal H_2	704 Helium He	720 Neon Ne	728 Nitrogen N_2	732 Oxygen O_2	740 Argon A	744 Carbon dioxide CO_2	744a Nitrous oxide N_2O
Boiling point @ 1 atm.	°F	-114.6	-198.3	-423.0	-452.1	-410.9	-320.4	-297.3	-302.6	-109.2*	-127.2
	°C	-81.4	-127.9	-252.8	-268.9	-246.1	-195.8	-182.9	-185.9	-78.4	-88.4
Freezing point	°F	-294	-299	-434.5	—	-415.5	-346.0	-361.8	-308.7	-69.9**	-131.6
	°C	-181.1	-183.9	-259.2	—	-248.6	-210.0	-218.8	-189.3	-56.6	-90.9
Critical temp.	°F	83.9	-50.2	-399.9	-450.3	-379.7	-232.4	-181.1	-188.1	87.9	97.7
	°C	28.8	-45.7	-239.9	-267.9	-228.7	-146.9	-118.4	-122.3	31.1	36.5
Critical pres.	psia	561	543	191	33.2	395.0	492.9	736.9	710.4	1070.0	1054.0
	kg/cm^2a	39.4	38.2	13.4	2.3	27.8	34.7	51.8	49.9	75.2	74.1
Latent heat (enthalpy)	Btu/lb	63.9	58.6	192.6	8.9	37.1	85.9	91.6	70.2	246.3	161.8
	kcal/kg	35.5	32.6	107.0	4.9	20.6	47.7	50.9	39.0	137.8	89.9
Gas density @ 70°F (21.1°C) and 1 atm.	lb/ft^3	.273	.228	.0052	.0103	.0522	.0724	.0828	.1034	.1144	.1146
	kg/m^3	4.37	3.65	.083	.165	.836	1.16	1.33	1.66	1.83	1.84
Wgt of liquid at 1 atm.	lb/ft^3	95.0	122.4	4.4	7.8	75.4	50.5	71.3	87.0	97.5	76.8
	kg/m^3	1521.8	1960.7	70.5	124.9	1207.8	808.9	1142.1	1393.6	1561.8	1230.2
Molecular wgt		104.5	88.0	2.0	4.0	20.2	28.0	32.0	39.9	44.0	44.0

* sublimation point
** 76.4 psia

TABLE 2.4. TEMPERATURE-PRESSURE RELATIONSHIP COMMON REFRIGERANTS-APPROXIMATE

Refrigerant Temperature		R-11		R-12		R-22		R-500		R-502		R-717 (ammonia)	
F	C	psig	kg/cm²g	psig	kg/cm²g	psig	kg/cm²g	psig	kg/cm²g	psig	kg/cm²g	psig	kg/cm²g
−100	−73.3	—	—	27.0*	686**	25.0*	635**	26.4*	671**	23.3*	592**	27.4*	696**
− 90	−67.8	—	—	25.7*	653**	23.0*	584**	24.9*	632**	20.6*	523**	26.1*	663**
− 80	−62.2	29.6*	752**	24.1*	612**	20.2*	513**	22.9*	582**	17.2*	437**	24.3*	617**
− 70	−56.7	29.4*	747**	21.8*	554**	16.6*	422**	20.3*	516**	12.8*	325**	21.9*	556**
− 60	−51.1	29.2*	742**	19.0*	483**	12.0*	305**	17.0*	432**	7.2*	183**	18.6*	472**
− 50	−45.6	28.9*	734**	15.4*	391**	6.2*	157**	12.8*	325**	.2*	5**	14.3*	363**
− 40	−40.0	28.4*	721**	11.0*	279**	.5	.04	7.6*	193**	4.1	.29	8.7*	221**
− 30	−34.4	27.8*	706**	5.5*	140**	4.9	.34	1.2*	30**	9.2	.65	1.6*	41**
− 20	−28.9	27.0*	686**	.6	.04	10.2	.72	3.2	.22	15.3	1.08	3.6	.25
− 10	−23.3	26.0*	660**	4.5	.32	16.5	1.16	7.8	.55	22.6	1.59	9.0	.63
0	−17.8	24.7*	627**	9.2	.65	24.0	1.69	13.3	.93	31.1	2.19	15.7	1.10
10	−12.2	23.1*	587**	14.6	1.03	32.8	2.31	19.7	1.38	41.0	2.88	23.8	1.67
20	− 6.7	21.1*	536**	21.0	1.48	43.0	3.02	27.3	1.92	52.5	3.69	33.5	2.36
30	− 1.1	18.6*	472**	28.5	2.00	54.9	3.86	36.0	2.53	65.6	4.61	45.0	3.16
40	4.4	15.6*	396**	37.0	2.60	68.5	4.82	46.1	3.24	80.5	5.66	58.6	4.12
50	10.0	12.0*	305**	46.7	3.28	84.0	5.91	57.6	4.05	97.4	6.85	74.5	5.24
60	15.6	7.8*	198**	57.7	4.06	101.6	7.14	70.6	4.96	116.4	8.18	92.9	6.53
70	21.1	2.8*	71**	70.2	4.94	121.4	8.54	85.4	6.00	137.6	9.67	114.1	8.02
80	26.7	1.5	.11	84.2	5.92	143.6	10.10	102.0	7.17	161.2	11.33	138.3	9.72
90	32.2	4.9	.34	99.8	7.02	168.4	11.84	120.6	8.48	187.4	13.17	165.9	11.66
100	37.8	8.8	.62	117.2	8.24	195.9	13.77	141.2	9.93	216.2	15.20	197.2	13.86
110	43.3	13.2	.93	136.4	9.59	226.4	15.91	164.1	11.54	247.9	17.43	232.3	16.33
120	48.9	18.2	1.28	157.7	11.09	259.9	18.27	189.4	13.31	282.7	19.87	271.7	19.10
130	54.4	24.0	1.69	181.0	12.72	296.8	20.87	217.2	15.27	320.8	22.55	315.0	22.14
140	60.0	30.4	2.14	206.6	14.52	337.3	23.71	247.7	17.41	362.6	24.49	365.0	25.66
150	65.6	37.7	2.65	234.6	16.49	381.5	26.82	281.1	19.76	408.4	28.71	420.0	29.53
160	71.1	45.8	3.22	265.1	18.64	429.8	30.21	317.4	22.31	458.7	32.25	490.0	34.45

*Inches of Mercury below 1 atm.
**Millimeters of Mercury below 1 atm.

displacement of the compressor used for a particular refrigerant but not particularly on the horsepower as it will be found that greater quantities of gas require about the same horsepower as lesser quantities due to the difference in gas densities and pressure differences between suction and discharge pressures.

The balance of the tables give a general knowledge of the various characteristics of the refrigerants. In choosing a refrigerant, the availability and cost should be considered carefully. All of the common refrigerants mentioned earlier in this chapter are readily available.

SECONDARY REFRIGERANTS

Introduction

Secondary refrigerants are normally fluid solutions that are cooled by a refrigerant and circulated as a fluid to pipe coils or other types of coolers. Heat is transferred to the cold fluid, warming it, and the warmed fluid is then pumped back to be chilled again by the primary refrigerant. Secondary fluids are often called brines regardless of their composition. In this context, a brine may be considered as any fluid or mixture of fluids with a freezing point lower than its use temperature.

Reasons for a Brine System

The following paragraphs are given to expand on the earlier brief discussion of brine systems. In the direct expansion system, the refrigerant itself must be circulated to the various evaporators located in the cold rooms. This entails relatively long lines under pressure and subject to leaks. These leaks, when they occur, are sometimes difficult to locate when halocarbon refrigerants are used and, in the case of ammonia, are annoying and can cause some disruption of operation. In addition, refrigerant piping is expensive to install and test. Long refrigerant suction lines can account for considerable pressure drop which decreases machine capacity and increases refrigeration operating costs. Low pressure drop to insure good operation means larger suction lines with increased first cost.

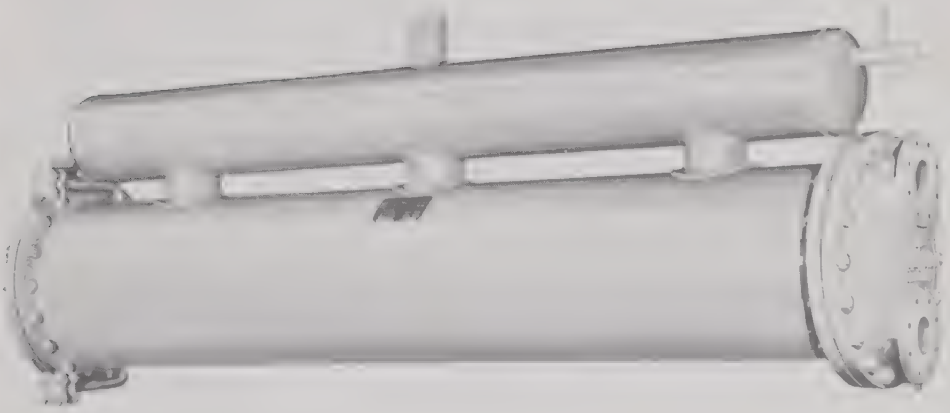
In many cold storage installations, the use of brine is seriously considered and used for a number of reasons. All of the refrigerant is confined to a single engine room where it is easy to control and leak check. Expensive refrigerant is saved since there are no long refrigerant lines and refrigerant losses from leaks are lessened since leaks should be fewer and easier to locate as they will occur in a small well defined area. Piping throughout the plant with brine lines is less critical than with refrigerant lines. Control of brine cooling units is simpler than direct expansion units with resultant simpler controls. The simplest type of control consists of a motorized valve opening and closing to regulate the flow of brine in response to a call from a thermostat. More sophisticated controls can be used but, in general, the control of brine units is of a simpler nature requiring less mechanisms than with direct expansion.

One of the disadvantages of a secondary cooling system is that it requires a double heat transfer. The refrigerant temperature must be lower than the brine temperature in order to cool the brine and the brine must be at a lower temperature than the product being cooled. This usually means that the refrigerant temperature is lower than would be used in an equivalent direct expansion system. Lower refrigerant temperatures mean more power used and higher operating cost. These factors must be weighed in determining what system is used. Brine pumps must also be used to circulate brine which is also an added power cost. The double heat transfer is at less disadvantage in a higher temperature range such as 35°F (2°C) and above. Some plants utilize a brine system for cooler rooms and direct expansion for freezers. In halocarbon refrigerant systems with a central engine room, a secondary refrigerant system may be preferable where long runs are involved.

Brine Coolers

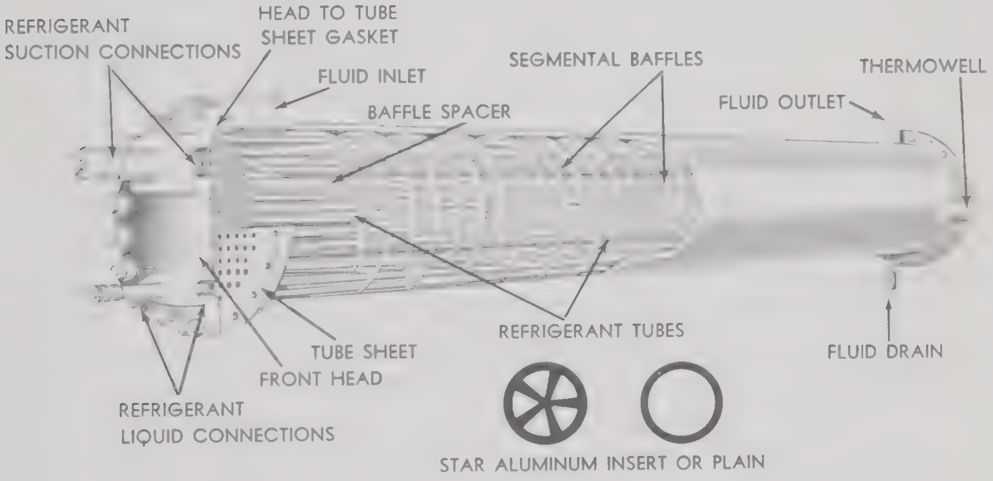
Fig. 2.1 illustrates the type of brine chiller usually used in a cold storage facility. This is known as a shell and tube brine chiller. In ammonia applications, the brine is pumped through the tubes in the vessel, there being numerous small tubes running inside the large outer shell and rolled tightly into heads at the ends. The large outer heads have ribs placed so that the brine being chilled may be directed back and forth several times before leaving the vessel. This is called a multipass chiller. Ammonia is introduced into the large shell and flows and boils around the outside of the tubes in the vessel and thus chills the brine passing through the tubes. As in all brine systems, a pump must be employed to circulate the brine.

Fig. 2.2 illustrates a shell and tube chiller that is normally used with a halocarbon refrigerant. In this case, the refrigerant is circulated through the tubes inside the chiller and the brine is pumped into the shell and around the tubes through a system of baffles. The brine around the outside of the tubes is cooled by the refrigerant inside the tubes. This method is used with halocarbon refrigerants to control the refrigerant velocity to insure oil return.



Courtesy Vilter Manufacturing Company

FIG. 2.1. SHELL AND TUBE BRINE CHILLER FOR USE WITH AMMONIA REFRIGERANT. BRINE CIRCULATES THROUGH TUBES OF VESSEL. AMMONIA INTRODUCED INTO SHELL AND AROUND OUTSIDE OF TUBES. TOP HEADER ACTS AS SURGE DRUM, OR ACCUMULATOR.


REFRIGERANT SUCTION CONNECTIONS
HEAD TO TUBE SHEET GASKET
FLUID INLET
BAFFLE SPACER
SEGMENTAL BAFFLES
FLUID OUTLET
THERMOWELL
TUBE SHEET
FRONT HEAD
REFRIGERANT LIQUID CONNECTIONS
REFRIGERANT TUBES
FLUID DRAIN
STAR ALUMINUM INSERT OR PLAIN

Courtesy Bohn Heat Transfer Division

FIG. 2.2. SHELL AND TUBE FLUID CHILLER COMMONLY USED WITH HALOCARBON REFRIGERANTS. THE REFRIGERANT IS EVAPORATED INSIDE THE TUBES WITH FLUID FLOW IN THE SHELL.

Heat Transfer in Brine Chillers

As stated previously, the use of a brine chiller involves a double heat transfer. If wide temperature differences are used, this can mean a severe penalty in capacity and horsepower in the use of a brine system over direct expansion. However, with good design and good brine flow characteristics, this difference can be minimized and an efficient brine system designed. In long brine lines, a leak of course needs attention at once, but is far less serious than in a direct expansion system. Brines are normally odorless and relatively inexpensive to replace and do little damage to most products. Leaks are also easier to repair than those in a refrigerant line.

Characteristics of Brine

When a small quantity of one substance, such as sodium chloride is dissolved in another, such as water; the resultant solution has a freezing point which is usually lower than that of the second substance. Further addition of the first substance will lower the freezing point of the mixture until a minimum freezing point is reached. This is called the eutectic point. Further addition of the substance will not lower the freezing point. If the temperature of the mixture is lowered below the eutectic point, the mixture will freeze. Brines of various substances may be chosen for operation at almost any temperature range. Low freezing point single fluids, such as R-11 may also be used as brines as well as other fluids with low freezing points. Ideally, a brine should have flow characteristics to allow it to be pumped with minimum horsepower.

Sodium Chloride Brine

Water solutions of sodium chloride (table salt) have been widely used in the past in ice making and in cooler room applications as well as other applications where brine at not too low temperature is required. The eutectic point in water solution is −6°F (21°C). Specific heat and thermal conductivity are high. The viscosity, or resistance to flow, is low thus pumping horsepower is not unduly high. Due to the fact that it has no harmful effects, it is often used in spray coolers in packing plants. Sodium chloride solutions can become acid and corrosive so the neutralization must be watched carefully to prevent deterioration of mechanical equipment which may come in contact with it. It can also have adverse effects on iron and steel.

Calcium Chloride Brine

The eutectic temperature of a water solution of calcium chloride is −59.8°F (−51°C). This point is reached with a concentration of 29.8% of anhydrous (dry) calcium chloride. This brine may be used for almost all cold storage requirements including freezer operation. It is somewhat more viscous than sodium chloride brine and requires more pumping horsepower. Calcium chloride brine can be very corrosive unless carefully neutralized. Fresh brine is usually alkaline and is neutralized with muriatic acid. Care must be exercised since the acid, by itself, is also very corrosive. Most warehouses in the past, where brine has been used, have used calcium chloride because of its low temperature capabilities.

Ethylene and Propylene Glycols

Inhibited ethylene and propylene glycol may be used as brines in a water solution but are not as popular as calcium chloride due to first cost. Ethylene is the less expensive of the two and has somewhat better properties of heat transfer and pumping ease than propylene. However, it can be toxic when in contact with food products and, where this is a possibility, propylene glycol should be used and is mandatory in some regulations. The glycols do not deteriorate to any extent and, when properly inhibited, are less corrosive than the salt brines. They can also be used at a lower temperature than salt brines and will remain fluid to −70°F (−57°C) or lower. Use at this low a temperature is not recommended as viscosity is high which causes high pumping costs.

Other Brines

Some brines used in work other than cold storage are perhaps worthy of passing mention as a matter of interest. Alcohol has sometimes been used for very low temperature work as well as some of the refrigerants themselves, such as refrigerant 11 and 12. The pure refrigerants usually have good characteristics for use as brines as long as they are used well below their respective boiling points. They can be pumped easily and usually offer no corrosion problems. Conversely, they are expensive and if temperature is lost, they may develope higher pressures subject to leakage. Their use is usually confined to specialized applications where cost is not the major consideration and certain desired results are mandatory.

Corrosion in Brine Systems

Brine piping usually consists of iron or steel pipe and other appurtenances. In the presence of air and water and some impurities, severe rusting and corrosion of lines can occur. It is mandatory that the brine in brine systems be kept in a neutral state. This can be done by the addition of chemicals. Brine should be checked at intervals and proper treatment added to prevent corrosion. The proper interval for checking brine samples can be found by trial and error; starting with frequent checks and then lengthening the intervals until they are as long as practical without significant change in the characteristics of the brine. It is necessary to know the total volume of brine in a system so that the proper amount of treatment may be calculated.

pH Scale

The pH scale has been developed to show the degree of acidity or alkalinity of a substance. A value of 7 on this scale indicates a balance between acidity and alkalinity and is thus the neutral point. Points below 7 indicate acidity while those above indicate alkalinity.

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3

Atmospheric Air

In a sense, atmospheric air might be classed as a secondary refrigerant in cold rooms because it comes in contact with a refrigerated surface such as a coil in a blower unit or a pipe coil in a refrigerated space and is cooled. The air then circulates, either by gravity or forced by a fan, to the various parts of the room to where it is warmed by absorbing heat and then returns to the coil for further cooling. This is exactly what happens with a liquid used as a secondary refrigerant except that the liquid is normally confined in a pipe or other enclosure. Even with secondary refrigerants other than air, the air usually is cooled by the secondary refrigerant so that there are two steps of cooling in addition to the prime cooling by the refrigerant. Atmospheric air is the air we breathe and is made up primarily of approximately 78% nitrogen, 21% oxygen and the balance in gases such as argon, hydrogen, xenon and krypton. For practical purposes, only the nitrogen and oxygen in the air are given consideration. In cold storage applications, atmospheric air is the transfer medium between the cold coil surface and the cold room and contents.

AIR MEASUREMENT

Dry Bulb Temperature

Dry Bulb Temperature is the temperature of the air measured with a thermometer. It measures the temperature or relative warmness of the air in degrees Fahrenheit, or Celsius, depending on the calibration of the thermometer. This temperature may also be measured by a thermocouple or other means. The dry bulb temperature does not take into account the moisture content of the air nor air motion. It is a measure only of the level of the temperature referred to a calibrated scale.

Moisture Content of Air

Atmospheric air can be completely dry to saturated with moisture. This moisture is in the form of a vapor and is invisible to the eye. It is actually in the form of a very low pressure steam. The amount of moisture in the air is measured in grains of water vapor per unit volume of air. This is known as absolute humidity. It takes no account of the dry bulb temperature of the air; but is a measure only of the grains of moisture. Table 3.1 gives the volume of air per unit of weight and also the heat content of the air for air containing no moisture. Table 3.2 gives some properties of saturated air, or air that has all of the moisture in it that it can hold. Most measurements of air are referred to sea level conditions. As elevations increase, the density of the air decreases and hence becomes lighter so that it takes more volume of air per unit weight. This does not vary greatly at normal elevations but on mountains and other high elevations it sometimes must be taken into account. Table 3.3 shows a comparison of air density at various locations.

TABLE 3.1. PROPERTIES OF DRY AIR

Temperature °F	Temperature °C	Volume in Cu Ft per Lb	Heat Content Btu per Lb Dry Air
50	10	12.84	12.005
55	12.8	12.97	13.206
60	15.6	13.10	14.406
65	18.3	13.22	15.607
70	21.1	13.35	16.807
75	23.9	13.47	18.008
80	26.7	13.60	19.208
85	29.4	13.73	20.41
90	32.2	13.85	21.61
95	35	13.90	22.81
100	37.8	14.10	24.01
105	40.6	14.23	25.21
110	43.3	14.36	26.41
115	46.1	14.48	27.61
120	48.9	14.61	28.81

Relative Humidity

A very crude but rather explicit definition of relative humidity may be taken as the amount of water vapor present in the air compared to the amount of water vapor the air could hold when 100% saturated. It is necessary to measure moisture and temperature together to determine humidity. If two thermometers are mounted side by side and a wet gauze placed over the bulb of one of them, then the thermometers moved rapidly in the air, the one with the wet gauze, or wick will read at a lower temperature than the dry bulb unless the air is fully saturated. This

TABLE 3.2. PROPERTIES OF SATURATED AIR

Temperature		Volume in Cu Ft per Lb	Btu per Lb	Grains Moisture per Cu Ft	Grains Moisture per Lb Dry Air	Latent Heat Btu per Lb Dry Air
°F	°C					
30	−1	12.40	10.92	1.8	24.0	3.71
35	1.7	12.55	13.00	2.2	29.1	4.00
40	4.4	12.70	15.21	2.8	35.5	5.62
45	7.2	12.85	17.63	3.3	46.0	6.84
50	10	13.00	20.26	4.10	53.42	8.26
55	12.8	13.16	23.18	4.96	64.35	9.97
60	15.6	13.33	26.40	5.80	77.28	11.99
65	18.3	13.50	29.99	6.85	92.49	14.38
70	21.1	13.69	33.99	8.06	110.30	17.19
75	23.9	13.88	38.49	9.45	131.16	20.48
80	26.7	14.09	43.55	11.04	155.61	24.35
85	29.4	14.31	49.28	12.87	184.17	28.87
90	32.2	14.54	55.75	14.94	217.27	34.14
95	35	14.80	63.08	17.28	255.81	40.27
100	37.8	15.08	71.44	19.94	300.70	47.43
105	40.6	15.38	80.99	22.94	352.9	55.78
110	43.3	15.72	91.92	26.31	413.6	65.51
115	46.1	16.09	104.46	30.01	484.3	76.85
120	48.9	16.51	119.02	34.34	567.1	90.21

TABLE 3.3. REQUIRED CUBIC FEET OF AIR AT HIGHER ELEVATIONS AS COMPARED TO SEA LEVEL

Elevations		Requirement For Same Duty as at Sea Level, Cu Ft
ft.	m	
0	0	100
1000	305	103
2000	610	107
4000	1219	114
6000	1829	123
8000	2438	131
10000	3048	141

lowered temperature is caused by the evaporation of the water on the wick and is called wet bulb temperature. The difference between wet and dry bulb reading is known as the wet bulb depression. This arrangement of two thermometers and a wick mounted in a simple frame with a swivel handle, so that the thermometers may be whirled in air, makes up a simple device called a sling psychrometer which is one of the most accurate methods of humidity measurement that can be performed with simple instruments. Humidity in the air makes a difference in the amount of heat that must be removed from air in cooling. Dry air requires the least amount of heat removal to lower its temperature. As the air becomes saturated with moisture, greater quantities of heat must be removed to lower the temperature of the air compared to the heat required to be removed for dry air. Table 3.4 shows comparisons of heat removal at different humidities and temperatures.

Temperature Effect and Relative Humidity

Cold air will not absorb as much moisture as warm air. At 32°F (0°C), a cubic foot of air will hold 2 grains of water vapor. At 50°F (10°C) it will hold 4 grains of water vapor and at 100°F (38°C) it will hold 19.5 grains of water vapor. These values are known as the saturation points for these temperatures. If water vapor in the amount of 1 grain is present in a cubic foot of air at 32°F (0°C), that cubic foot of air would be 50% saturated. If that cubic foot of air were warmed to 50°F (10°C) it would be 25% saturated and at 100°F (38°C) it would be just slightly over 5% saturated. This degree of saturation is called Relative Humidity. Air that is saturated has practically no drying effect. As the relative humidity lowers, the air then has the ability to pick up moisture. In refrigeration applications, as the difference between air temperature and refrigeration temperature is increased, the lowered refrigerant temperature will tend to condense moisture out of the air thus lowering the relative humidity of the air. This air then having the ability to absorb moisture will tend to pick it up from products stored in a room with a consequent drying out and deterioration of the product. Conversely, if the difference between air temperature and refrigerant temperature is kept low, more moisture will be left in the air and it will be at a higher relative humidity and will not be able to pick up as much moisture from stored products. This condition is desirable in most cold storage rooms. Variations from about 65% relative humidity to about 90% relative humidity can be achieved by varying refrigerant vs air temperatures in cold storage cooler operations.

Humidity is also important in freezer rooms since air below freezing contains moisture. Low relative humidity in freezer rooms can lead to severe product deterioration through loss of product moisture. Because saturated air at sub freezing temperatures contains only a few grains of moisture, temperature differences need to be kept as low as practicable to prevent undue drying (desiccation) of the products stored.

Dew Point

The dew point of air is that temperature at which moisture will start to condense out of the air in the form of water. As an example, if air is at 100°F (38°C) and at 100% relative humidity and the temperature of the air is reduced, moisture will condense out of the air. If the air is only at 70% relative humidity, then the temperature would have to be dropped to a little below 89°F (32°C) before moisture would condense out of the air. A reliable method of finding dew point is to fill a polished metal cup with water at room temperature. Ice is then added to the water a little bit at a time, stirring the mixture and observing the lowered temperature of the water and the outside of the cup. When the temperature of the water, and the surface of the cup, reach the dew point, the condensation can be observed on the polished surface of the cup.

Humidity Control

Humidity control in cold storages is quite often ignored. This does not necessarily cause bad results if the original design of the plant has been worked out carefully to give the required humidities in the various cold rooms. Generally, in freezers, the temperature difference between room temperature and refrigerant temperature should be kept at 10°F (5.5°C) or less. This will provide humidities in the room that are acceptable. Generally in storages of frozen commercial products, the products are packaged to prevent loss by evaporation. There are no storage conditions that require low humidities in freezer storage.

Cooler rooms may be required in varying humidities. Unless adequate provision and control is at hand, some specialized loads may be impossible to handle and should not be attempted. In the cooler range of 34° to 40°F (1° to 4.5°C), humidities can generally be controlled by varying the temperature difference between room and refrigerant. This can be done with refrigeration suction pressure controls and thermostats and humidistats. Suction pressures with their resultant temperatures can be varied upward from the plant pressure to any point desired without difficulty and with proper controls, these limits can be maintained pretty well wherever desired.

Where low humidity is desired, as in a candy room, it is usually necessary to employ some type of reheat. The coil temperature is set low enough to remove moisture required and then to prevent excessive cooling of the room, heat is added to the air to maintain the proper temperature. Chemical means may also be employed to lower the humidity by absorption of a substance such as a hygroscopic brine which is then reactivated and used over again. This process has a rather high first cost but sometimes requires less energy than a reheat.

Where very high humidity is required, it may be accomplished by the introduction of moisture into the air by a very finely atomized water stream or by the introduction of steam into the air stream. This is a relatively simple process. Care should be taken in high humidities to keep refrigerant temperatures as high as possible so that excess moisture is not removed by the coils which then must be added by the humidifier.

Psychrometric Charts

Psychrometric charts are designed to assist in designing and evaluating conditions of air. Figure 3.1 is a chart designed for air conditioning and higher temperature cold storage conditions and Figure 3.2 is a chart designed for low temperatures. From these charts, almost all of the characteristics of the air conditions can be determined. As an example, on the air conditioning chart, air at 100°F dry bulb and 50% relative humidity. Locate 100 deg. on the bottom dry bulb temperature line. Rise vertically to the 50% relative humidity line and then on the diagonal line to the wet bulb and dew point line which shows a wet bulb temperature of 83°F and also a total heat of the air at that condition of slightly less than 47 Btu per pound of air. Directly to the left from the intersection of the 100° line and 50% line is the dew point of 78°F. To the right may be found the grains of moisture per pound (147 gr.).

Design for Odor and Taste Control

Odors penetrating into cooler and freezer storage rooms can contaminate some foods (not properly packaged) and especially those containing oils and fats. These odors, if severe, can actually lower the grade of the product being stored with subsequent dollar loss. In freezer applications, odor penetration can occur to some extent, but is not as severe as in cooler storage. There are many methods used to combat odors, probably none of which will be 100% satisfactory.

Activated charcoal has the property of being able to adsorb odors on its surfaces and is frequently used, particularly in coolers, as an odor control. After the surfaces become saturated, they can be reactivated with heat. However, quite frequently the old charcoal is thrown away and new charcoal substituted.

Various chemical washes are available that tend to remove odors and at the same time destroy some of the sources of odor. Filtered fresh air may also be used to dilute odors. This imposes a considerable refrigeration load and any fresh air introduction should be monitored to be sure the load of the fresh air to bring it to room temperature does not exceed the capacity of the refrigeration equipment. Sometimes a room may be taken out of service and fresh air pumped through for an extended period.

Fortunately, with good housekeeping in storage rooms and surrounding areas and with prepackaged products that are mostly in use today, odor is not a large problem in the cold storage industry. Cleanliness is a far better preventative than other methods as cures.

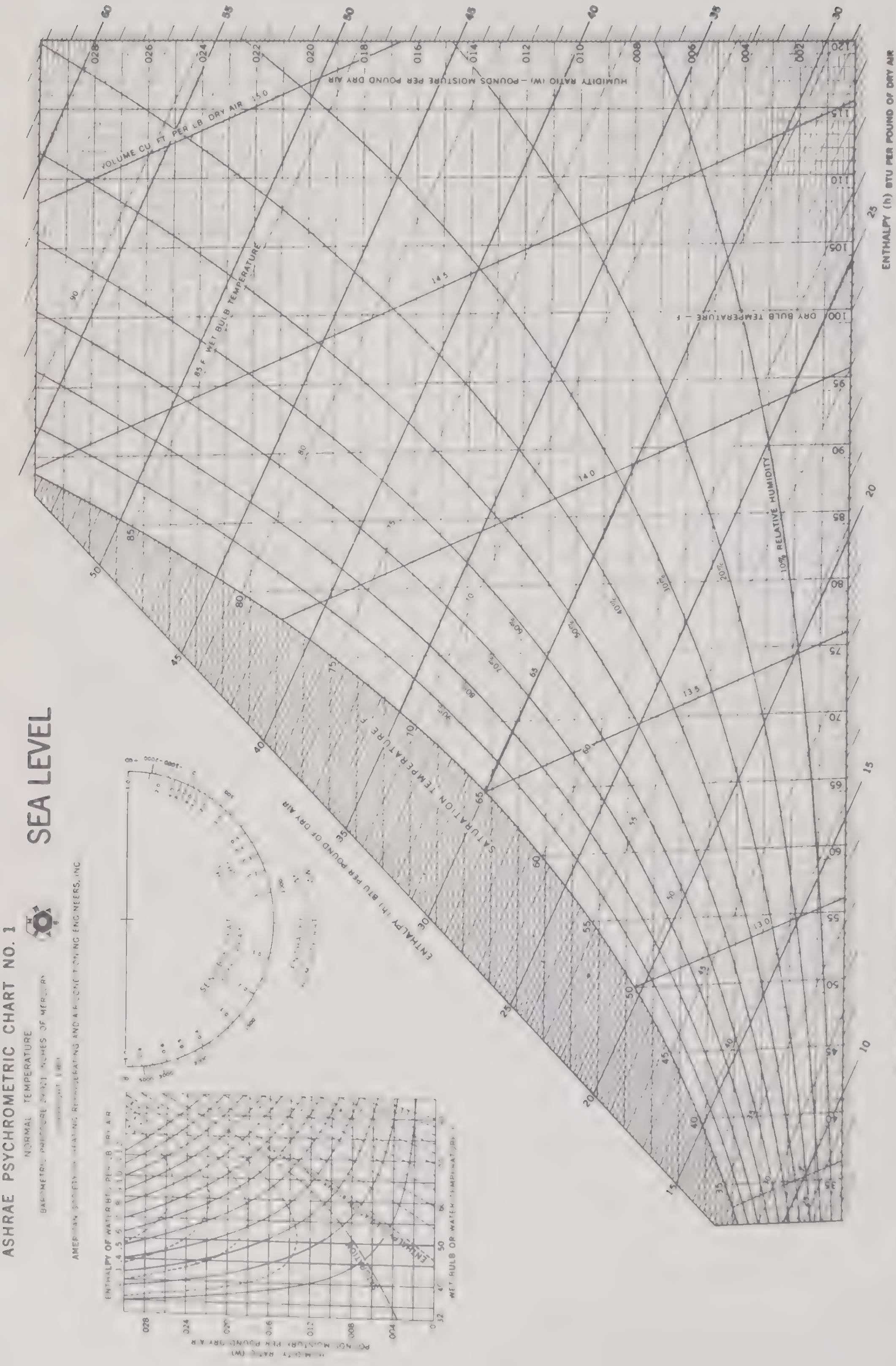

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FIG. 3.1. AIR CONDITIONING PSYCHROMETRIC CHART

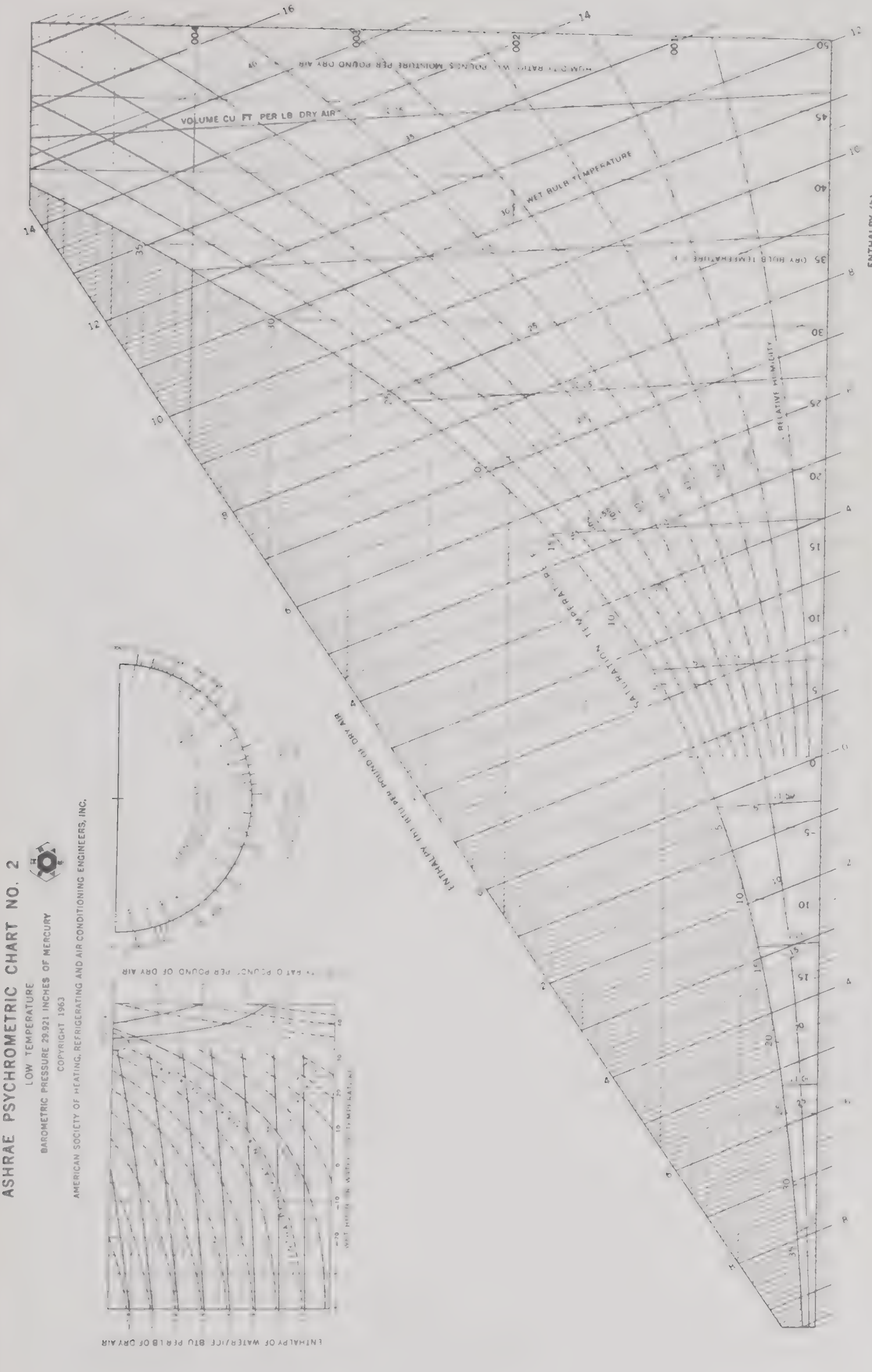

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FIG. 3.2. REFRIGERATION PSYCHROMETRIC CHART

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4

Energy Conservation

In recent years the world has gone from a position of endless cheap energy, with no particular thought of conservation, to a condition of constantly rising energy costs and threatened energy shortages. Many predictions have been made as to how long our present known energy supplies can last and these are at wide variance with each other. Alternate energies, such as nuclear power, solar energy, wind power and others are being pursued with enthusiasm but as complete substitutes are apparently still in the future. Be the shortage as it may, there is one fact that cannot be denied and that fact is that the cost of energy is almost constantly increasing and about the only prediction that can be made is that it probably will go higher as time passes. It is also rather apparent that our known reserves of fossil fuels is finite rather than infinite, as we persisted in believing through the years.

There are really two main reasons for conservation of energy. First, if fuels are really in short supply, there is a duty to future generations to be as sparing of the remaining supplies so that some may be left for the future and to assure adequate supply until other sources may be developed.

There is also a practical reason to conserve. The constantly increasing cost of energy makes conservation also self preservation to stay in business. Almost all businesses are concerned with energy, either directly or indirectly so their costs of doing business are increased as energy prices keep on rising. It thus behooves us to take whatever steps we can take to operate in an efficient manner and stop waste where possible. This is particularly true in the cold storage industry since it is a relatively large user of power in various forms and this direct energy use is a good share of the operating expense.

HISTORICAL

After World War I, the refrigeration industry started to grow with considerable rapidity and the ice plant came into its own as a producer of refrigeration for many uses. This refrigeration was produced in the form of ice which was sold to homes, industry, stores, ice cream parlors, etc. It was the one great source of cold at that time. To make ice requires power. Power in that period was relatively expensive considering the value of the dollar at that time. Since ice companies were in business to make a profit, they demanded and received efficient ice making plants. Large condensers were used and all of the equipment was somewhat more than adequate to the task assigned it. Great attention was paid to the energy input per ton of ice produced and the plants produced in the 1920's and subsequent years were perhaps as efficient in their use of energy as any produced since.

World War II brought on a surge of refrigeration with the advent of frozen foods in quantity. Also the home air conditioning sparked a great surge in the manufacture of small refrigeration compressors. The first air conditioners were generally water cooled with cooling towers and were not too inefficient. Gradually, competition caused the curtailing of extras and condenser surfaces were cut to a minimum. About this time the air cooled condenser was introduced to the mass market as a substitute for water cooled equipment. With cheap energy and problems of maintenance with water cooled condensers, it caught the public fancy until today even some large commercial jobs using the halocarbon refrigerants are air cooled. Competition again forced the curtailment of condenser surface and generally boosted power consumption per ton of refrigeration. With cheap power, this did not particularly concern anyone.

The advent of the energy shortage with its attendant increased power cost will surely, if it has not already, bring on a resurgence of desire for more efficient systems. Some standards of efficiency have been set, particularly for the smaller sized systems, which have been somewhat helpful in increasing efficiency. However, in a great many facets of refrigeration systems, no real standards are in existence for best efficiency and lowest operating costs.

It would seem that we have come full circle and must now revert back to some of the early standards of efficiency of machinery. The halocarbon industry which was born in flush times should begin to design for a peak efficiency that has not often been achieved in times past. This can be done but will entail a reversal of some of the design thinking with respect to equipment selection.

AREAS OF CONSERVATION IN REFRIGERATION INSTALLATION

Conservation of energy (savings in power) is not any one big item but a series of relatively small savings in many different areas. When added up, they can result in significant reduction in energy usage with consequent savings in operating cost. Following are several typical areas where savings can be affected. They are mentioned here as a summation of items only. More detail regarding these items will be found in subsequent chapters.

Insulation

The losses through insulation in a cold room represent a substantial part of the total refrigeration load on that room. Standards that have been adhered to for many years now need a second look. High energy costs are making increased insulation of refrigerated enclosures more appealing. Before subscribing to the old standards, it is well to look at the economic payout of increased insulation against increasing power costs.

Compressors

Heavy duty refrigeration compressors usually run more efficiently when not pushed to their top speeds. Choosing compressors at somewhat less than top speed can often be justified by lowered power consumption per ton of refrigeration at a more efficient speed. On larger loads, a multiplicity of compressors can sometimes effect savings over one or two large compressors and at the same time provide more redundancy by breaking the load into smaller segments. By shutting down machines under light loads, more power can usually be saved than utilizing capacity controls on large machines. Good maintenance, particularly preventive maintenance can help to keep compressors in top efficiency.

Condensers

Significant savings can be made by condensers of adequate size for the lowest possible practical head pressure. Ammonia installations have normally been made to operate with a condensing temperature of 95° to 96°F (35° to 36°C) with water cooled condensers and with outside conditions of 100°F (38°C) dry bulb and 78°F (26°C) wet bulb temperatures. In opposition to this, halocarbon systems have generally been designed to operate at 105°F (41°C) under the same outside conditions. No particular reasoning can be assigned to why this is so. It is not difficult to operate halocarbon refrigerants at the same conditions as ammonia. In addition to a considerable savings in power, the cooler operation and increased condenser surfaces tend to scale at a slower rate thus giving better account of themselves for a prolonged period over the higher temperature operation.

Air cooled condensers are used mainly with halocarbon refrigerants since the high discharge temperatures of ammonia gas at the higher condensing pressures occasioned by air cooled condensers may tend to damage the oil and cause some breakdown of ammonia. Air cooled condensers should be sized for minimum temperature differences of 10° to 15°F (6° to 8°C) between condensing temperature and ambient air temperature. This is about the practical limit. High temperature difference can, of course, lead to high power costs.

Consideration should also be given to means of controlling flow of refrigerant to evaporators so that an artificially high head pressure need not be maintained to insure proper flow. There are flow devices and controls that will allow head pressures to decrease (within limits) as the outside condensing medium temperature decreases. These devices do not represent significant cost increase in a large cold storage but may be expensive for the small installation. They should be investigated, in any event, when an installation of more than a single small room is contemplated.

Evaporators

Evaporators need to be sized with a difference normally of no more than 10°F (6°C) temperature difference between room temperature and refrigerant temperature. By holding a small temperature difference, the refrigerant temperature is kept at its highest suction pressure and since the horsepower per ton decreases as the compressor works on higher suctions; the low temperature difference can effect compressor power savings. Also, the compressor will pick up capacity as the suction pressure increases. If multiple evaporators can be used without duct work, the fan horsepower will be less than using fewer large evaporators with duct work through which the air may be forced. Air distribution is not as critical in a cold storage room as in an air conditioned space.

Piping

Piping should be adequate to carry the amount of refrigerant required without undue pressure losses. High line pressure drops make more work for the compressor since it must lower its suction pressure to overcome the line drop. Pipe sizing is somewhat more critical for halocarbon refrigerants than for ammonia due to oil return problems that require certain minimum velocities, particularly in risers.

OPERATION

Careful operation of cold storage plants can lead to great savings. Most engine rooms are automatic in modern plants and are programmed to give efficient operation. An automatic plant does not mean an unattended plant however, and top flight maintenance and knowledge of the control system is the requirement of a good operator. Unless the plant is maintained and the control system checked and kept operative, inefficient operation can result.

Equally important to the good operation of refrigeration machinery is good operation of the cold storage facility itself. Doors left open longer than necessary can waste a tremendous amount of refrigeration. Inattention to insulation breaks and generally poor housekeeping can cost a considerable amount in power. Lights left on when rooms are not in use and other carelessness in the warehouse are as costly as poor refrigeration equipment performance.

SUMMARY

Power savings in a cold storage facility come about as a result of good initial design for the best possible efficiency of refrigeration operation plus best insulation thickness plus good operation of the complete facility at all times. Engine room personnel and warehouse crews should act as a single team rather than as adversaries, as sometimes happens. Energy costs are rapidly climbing to a point where the luxury of competition between crews can no longer be tolerated, except that competition of who can do the best and most cooperative job. High production of one part at an expense of some other part is not economical, but wasteful.

Generally speaking, a cold storage facility is a long time investment. First cost is certainly a factor since finances are usually limited. However, since operating costs are on the increase, a little more investment to obtain more efficient and reliable equipment can result in increased profits at a later date and may mean the difference between staying in business or getting out at some future point down the road. This is expressed rather succinctly by the old saying that it is not hard to spend dollars when you know they will come home with friends. This has never been more true than at the present. What the future holds with respect to energy supply and energy cost, no one knows, but it is pretty certain that it will cost more as time goes on and that the supply will probably decrease before new sources are discovered to increase it as much as is needed. It is not a bright picture but careful planning can lessen the impact.

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5

Small and Intermediate Sized Cold Storage

HISTORICAL

The value of natural ice was recognized in ancient times as a preservative for foods and also was used to cool the drinks of the nobility. In temperate zones, ice was sometimes imported from high mountain passes as a novelty for the very rich. Its use was strictly limited however, since the vast majority of the people were too poor to even consider, or know, of such a luxury. In arctic regions, food preservation by cold was early used since there was an abundance of ice and during the warmer weather, heavy igloos of ice were used as preservative chambers for foods.

During the early days of the United States, ice cooled meats and fish were preserved by natural ice in the northern parts of the country. The ice was harvested from rivers and ponds during the winter months and stored in heavily insulated ice houses. These ice storages were often insulated with sawdust. The ice was then used as needed during periods of warm weather. At best, this was a somewhat uncertain method of food preservation and entirely dependent on the weather.

Mechanically Refrigerated Cold Storage

Benjamine M. Nyce built his first storage units for storing Indiana apples using ice cooling with circulating pans. He took out his first patent in 1858 on a cold storage house design. Nyce continued to expand his building program and eventually introduced machine refrigerated cold storage houses from Cincinnati to New York City. The first refrigerated frozen meat processing and storage is believed to be credited to Dr. Henry Peyton Howard of San Antonio, Texas. In 1868, Dr. Howard constructed a 25 foot × 50 foot cold storage room in New Orleans for frozen beef. In this period however, the accepted methods of preservation by pickling, smoking and drying without refrigeration were used mostly and the refrigerated product was still somewhat of a novelty. In the northern United States some freezing of meat was done during the winter months when fresh meat was packed in ice and sometimes ice and salt mixtures and allowed to freeze when the ambient temperature was below freezing. This was a rather haphazard method and was normally done by individuals for their own use rather than as a commercial enterprise.

As mechanical refrigeration processes began to be developed in the latter part of the nineteenth century, chilled and frozen foods became a reality in the market place and at the turn of the century, cold storage of numerous items was done in some quantities.

SMALL COMMERCIAL WAREHOUSES

Early cold storage temperatures were usually above 32°F (0°C) and even as late as 1930, 80% of the cold storage capacity in America was at temperatures above 32°F (0°C). The principal demand for storage temperatures of 0°F (−18°C) was for ice cream and butter storage. Very small rooms and ice cream cabinets used ice and salt mixtures to obtain lowered temperatures required. Hundreds of ice storage houses served as vegetable and fruit cold storage facilities. The locker storage industry spent its infancy in the ice house in the first quarter of the twentieth century.

Many of the cold storage plants of the period prior to World War I were associated with ice plants. The refrigeration equipment and operating personnel for producing ice and maintaining the cold storage rooms were the same. Sometimes the same and sometimes different business managers operated the ice plant and cold storage.

The early freezer storage rooms were operated as a community service and quite often at a financial loss. A demand for frozen foods in the mid-twenties created a demand for frozen food storage space. Almost simultaneously the demand for locker storages in the rural areas of North America by farmers and ranchers made small freezing and storage plants a necessity. While the Great Depression reduced the investments, it also created a demand in many regions for storage facilities in which people could keep their perishable produce, either home grown or purchased in bulk. The locker plant industry probably suffered less from the depression than most industries since it filled a demand nurtured by the depression; that of storing food products that could be purchased more cheaply in bulk and also home produced produce.

With the advent of the halocarbon refrigerants, the small cold storage spaces surged to a tremendous growth as equipment became lighter and less expensive to produce. Following World War II, the frozen food industry began to grow by leaps and bounds and the locker plants gradually faded from the scene except for a few isolated instances. Distribution points for frozen foods were established and freezer space instead of being almost an offshoot of cold storage became the principal type of space built into the newer warehouses.

Cooler and freezer cold storage warehouse space may be divided generally into two categories: (1) General warehouse space which is frequently known as public warehouse space in which several different products are stored, all requiring about the same conditions and also with different owners. (2) Specific warehouse space which is devoted to a specific product requiring certain conditions which set it aside from other rooms. In the small and intermediate sized cold storage rooms, the ownership is usually confined to one company which stores their own products since profitable operation of cold storage requires considerable size in rooms. However, in many instances, smaller rooms are constructed in larger warehouses for lease to individual users.

Cold storage rooms are often designated as small, intermediate and large rooms. There is no clear cut definition as to the size limits of these categories. As a starting point, a small room might be classed as any room up to a thousand sq ft (93^{m2}) to 3000 or 4000 sq ft (279 or 372^{m2}). Anything above this size would be considered a large room. This is purely an imperical rating for reference in this volume and not intended as any kind of a standard since the definition of sizes changes from time to time and locality to locality.

Storage rooms may also be categorized according to use such as meat, poultry and fish cooler and freezer rooms, fruit storage rooms, nut storage cooler and freezer rooms, general produce cooler rooms and frozen food freezer storage. In addition, some freezer rooms are also equipped for freezing of products.

COLD STORAGE TEMPERATURES

Temperatures are varied in cold storage rooms depending on what is to be stored and length of storage. Some general categories may be mentioned and most storage areas will fall into one of the following temperature ranges.

High Temperature Storage

High temperature storage is used for semi-perishable merchandise such as canned vegetables and other products. Temperatures are usually kept under about 80°F (27°C). Actually this type of storage qualifies more as air conditioning than refrigeration and is used to prevent excessive summer heat from shortening the life of canned foods and some other items.

Medium Temperature Storage

Medium temperature storage normally falls in the range of from 32°F (0°C) to 50°F (10°C) and covers a wide range of products that need to be stored at above freezing temperatures. In the higher range, humidity control is quite often of importance and in the lower part, high humidities are most often needed. Candy and some other specialty items often require the higher temperature humidity controlled storage. Fruits, nuts and other food items come at the lower end of the scale.

Freezer Storage

Freezer storage is used for the storage of pre-frozen foods including vegetables, meats, fruits, fish, fowl, butter, ice cream and other related items. Freezer temperatures will generally be from 0°F (−18°C) to −10°F (−23°C) with the present trend near the low end of the range. This allows the product to be at a sufficiently low temperature to prevent thawing during handling from storage to refrigerated distribution trucks, or from store freezers to the display cases.

Sharp Freezer Storage

Sharp freezers are kept at a somewhat lower temperature than regular freezers and are sometimes used to freeze some products such as boxed meat or carcass meat that do not require rapid freezing and also to hold frozen products. Loading is figured on the basis of room losses plus freezing load. This type of freezer is normally kept at about −20°F (−29°C). Newer warehouses do not use a great deal of this type storage except for special applications since holding freezers at the lowered temperature is costly and the space required to freeze is expensive as freezing time is somewhat long.

Blast Freezers

Blast freezers are used in many cold storage warehouse installations. In this type of freezer, the product is piled in a relatively compact pattern often called a tunnel and air at temperatures of −20°F (−29°C) to −40°F (−40°C) is blown, or blasted, over the product to effect a rapid removal of heat and moderately fast freezing. The blast freezer is compact and allows the freezing of large tonnages of product in a relatively small space. The product is then removed and stored at regular freezer storage temperatures where it can be stacked for maximum tonnage without spreading the product for freezing air circulation. Blast freezers are more often found in large cold storage installations since the amount of product to be frozen needs to be considerable for economical operation and the blast frozen products then require substantial space for storage.

Miscellaneous Storage Conditions

There are a number of specific purpose cold storage rooms which will be discussed in later chapters. There are also many different freezer methods that are not particularly considered in the planning of a cold storage unless process work is to be done for a specific processor in which case the particular freezer or process cooler is built to the specifications of the lessee who will be using or leasing the facility.

LOCATION OF STORAGES

Small and intermediate size cold storage facilities are most often a part of a process industry or store distribution center and the location is then set by the location of the other facilities of the processor or distributor. Small storages also may be found as a part of a large cold storage complex and leased to individuals or companies for their own use. The location is then dictated by the location of the entire cold storage facility.

SMALL INTERMEDIATE COLD STORAGE

As stated earlier, the first cold storage of any real consequence was part of an ice plant operation. Very early in this phase, products to be stored were actually placed in ice storage rooms. These products were usually meat products and were frozen in the ice storage vault which was normally held at a temperature of 20°F (−7°C) or above. This resulted in rather slow freezing which did not improve the product but did allow it to be held for longer periods than when unfrozen. Gradually, ice plants began to free a room which could be held at temperatures above freezing for the storage of perishables for short time storage. From this type of storage, evolved the locker storage plant where individuals could have their own locked compartment. Also by the time the locker plant came into being, the freezing of meats and vegetables had become popular and the technique had advanced. Most locker plants consisted of a freezer in which individual lockers were located, a sharp freezer or semi-blast where produce and meats were frozen and a chill or aging room where meat products were stored until frozen and hung for aging as required. Other facilities included were a processing room for preparing foods for the freezer or sale. Sometimes slaughtering facilities were also included. The plants provided a real service and helped a great deal in the acceptance of frozen foods by the people.

Small coolers will most often be found in markets where meats and other food products may be maintained under refrigeration until sold and also back-up stock for the refrigerated show cases. Convenience stores also have coolers with display doors so that they can be self serving to the customers. These coolers may be as large as 500 sq ft or more (47 m^2).

Small freezers may be found in supermarkets in some instances. Also small freezer spaces may be partitioned off in a large room and leased to individual distributors of frozen foods for their use. Small dairies may also have a small freezer room for the storage of ice cream and frozen novelties.

Intermediate sized rooms are quite often found in grocery distribution centers and in process plants where processed foods or incoming materials must be held at specified temperatures. This includes both freezers and coolers. Large cold storage installations also may divide some of their space into intermediate sized rooms for lease to individual companies who desire to use their own help for distribution and handling of products. Dairies quite often have a number of intermediate sized rooms both cooler for fresh milk products and freezer for frozen products.

SMALL COOLER FREEZER LOADS

It is extremely difficult to predict or catalogue loads for small or intermediate sized coolers. Condition of expected products as to temperature is a varying factor in most storages. Type of insulation used as well as frequency of door use, number of doors, etc., are all factors in determining loads on coolers. As a very general rule of thumb, coolers up to 1000 sq ft (93m^2) and up to 10 ft. ceiling height will require a ton of refrigeration for each 225 sq ft (21m^2) of floor space. Freezers of like size will require a ton of refrigeration for each 150 to 200 sq ft (14 to 19m^2). These assumptions are based on rooms with adequate insulation, moderate use and storage only and with only minimum product load. As stated before, these loads are only approximate. Each installation has its own peculiarities and special considerations and it is not possible to give any rule of thumb that will cover all cases.

INTERMEDIATE COOLER AND FREEZER LOADS

Intermediate rooms up to 5000 sq ft (465m^2) will have wider variations in tonnage than small rooms since they are usually put to a wider variety of uses. Coolers in this size range, and 15 to 20 ft. (4.5 to 6.1) ceiling height, may require a ton of refrigeration for each 250 to 325 sq ft (23 to 30^2). Freezers in this general size range may require a ton of refrigeration for each 200 sq ft (19^2) of floor area. These assumptions are based on normal room usage in loading and unloading and with minimum product load and with adequate insulation for the temperature encountered.

Cooler temperatures above are based on 35°F (2°C) and freezer temperatures of 0°F (−18°C) to −10°F (−23°C). It is essential that the above figures be used only as a casual estimate of tonnages required and not as any final figure since many variables affect the actual loads of cold storage rooms.

Most of the small and intermediate sized rooms, when isolated from a large central plant, are refrigerated with one of the halocarbon refrigerants and either water or air cooled condensing systems.

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6

Large and Intermediate Cold Storage Facilities

HISTORICAL

Prior to World War II, most cold storage space consisted of coolers at above freezing temperatures with very little space devoted to either freezers or freezing of products. The small locker plant had created some taste for frozen food products, but this was mostly on a local level and the idea of commercial quantities of frozen food products had not yet been born, or at least, had not been tried on any large scale. The large commercial cold storage plants were devoted, in a large part, to the storage of eggs, apples and other cooler products at above freezing temperatures. Freezer storage was available in rather limited amounts and mainly used for the storage of frozen fish, some meats, butter, ice cream and a few other products. Some experimental work was being done on freezing methods for commercial use but the actual market impact of frozen foods had not yet taken place.

The advent of World War II saw a tremendous upswing in the demand for both cooler and freezer space. Many cold storage plants were erected by the government for military stores. Large amounts of food were frozen and this created a high demand for almost non-existent freezer space. Many commercial cold storage plants hastily converted existing cooler rooms to freezers. This was usually accomplished by the addition of surface, usually in the form of pipe coils, to the existing refrigeration coils in the room and by lowering the evaporating temperature of the refrigerant within the coils by the addition of new compressors or diversion of existing compressors to the freezer load. Insulation was sometimes added to the existing insulation but more often was not. The resultant freezer space was makeshift at best. In some instances the insulation, not being properly sealed and of inadequate thickness for below freezing temperatures, would pop off of the walls with distressing results to the stored product. Some insulations stayed in place and some were propped up by wood shoring to allow use of the room. Although results were sometimes disastrous with converted rooms, these rooms did provide sorely needed freezer space even though conditions were less than ideal. A goodly number of these converted rooms were completely ruined by the conversion and had to be rebuilt at a later date. Serious problems were often encountered when a room was returned to cooler service or thawed out for reworking. As the room defrosted, it quite literally came apart as the ice and frost were melted since the ice and frost that had accumulated during freezer use was about all that held the room together. Some of these defrosting rooms almost truly "went down the drain."

After the conclusion of the war, a considerable boom was experienced in demand and construction of cold storage space and in increased use of freezer space. The form and concept of the cold storage plant also changed radically over that used prior to the war. Most of the cold storage plants erected up until the 1940s were multi-storied in nature and often erected in congested parts of the city. The post war period saw the rapid development of materials handling equipment such as forklift trucks with palletized operation and other forms of labor saving equipment. Battery driven fork trucks were improved and equipped for use in cold rooms. Also rapidly rising labor costs dictated faster and more efficient handling of merchandise. New warehouses were designed for palletized operation with forklift trucks to speed handling and permit more economical use of space. Other battery powered and engine powered equipment was developed for handling of merchandise in a more

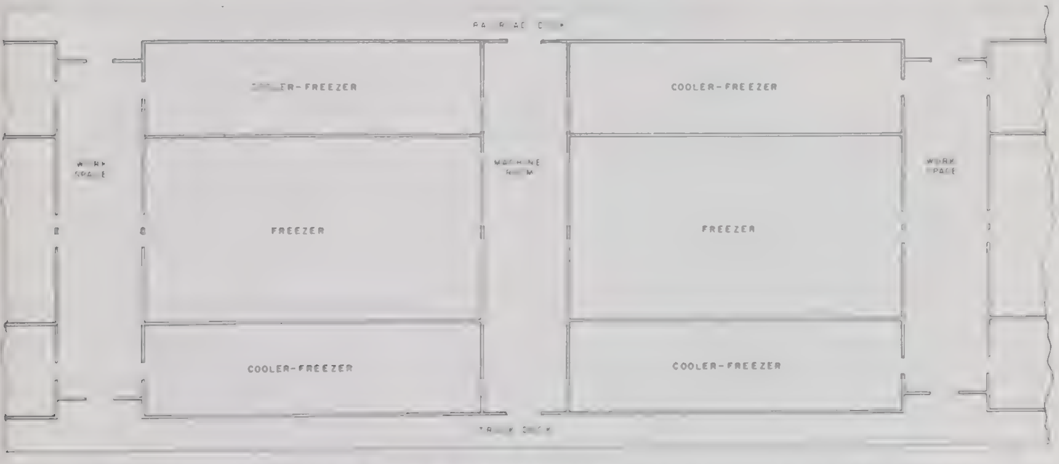
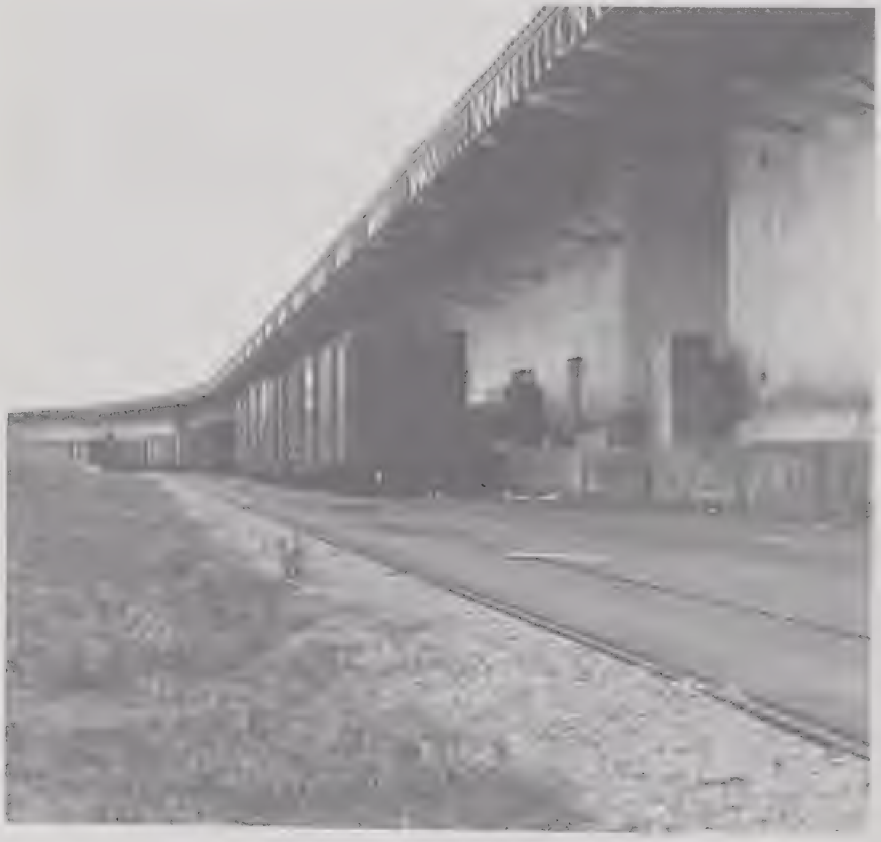


FIG. 6.1. TYPICAL PART FLOOR PLAN FOR LARGE WAREHOUSE WITH TRUCK AND RAIL LOADING FACILITIES.

Note work bays extending through warehouse for ease in working either dock. Many variations are possible to achieve good operation.

efficient manner. High ceilings in cold rooms also came into being since forklifts could effectively use higher piling heights efficiently. The new warehouse evolved as a single story facility usually out of the congested district of the city. Large rooms were used for the most part with work spaces between rooms and relatively wide dock spaces, all in the interest of fast economical handling of merchandise both in and out of storage. Enclosed and sometimes refrigerated docks were added to some plants to help maintain product integrity by preventing extreme heat from ever getting to the product in its transfer from truck or car. In other plants, the semi-enclosed work space between cold storage rooms was used as a safeguard and temporary storage in the movement of product. Figure 6.1 shows the floor plan of a typical cold storage plant in part. Most plants use this type of plan with variations as to the facing of the rooms, dock placement and work spaces. Each plant must be worked out to suit the preference of the plant owners and any storage conditions peculiar to that particular facility.



Courtesy Alford Refrigerated Warehouses

FIG. 6.2. VIEW OF CONTINUOUS DOCKS WITH DOUBLE RAILROAD TRACKS. SECOND TRACK USED FOR CAR STORAGE.

Pre-World War II cold storage plants were almost always refrigerated by means of banks of pipe coils with the refrigerant, or cold brine, inside the pipes and the room air flowing by gravity over the outside. These coils required considerable space in which to hang. They were difficult to defrost. They also required adequate structure to stand the weight of the coil plus any ice accumulation. As newer plants evolved, so did the form and nature of the coils used. The blower coil, consisting of a pipe bundle encased in a housing with a mechanical fan driving air over the coil and out into the room, came into use. The forced air at higher velocities over the coil decreased the amount of coil surface required. A little later on, metal fins were placed on the coils thus increasing the effective cooling surface greatly and giving a compact cooling unit. Present day evaporators usually follow this general form. The new blower coils were small and compact compared to the old pipe coils. They required little if any additional building structure bracing and the first cost was considerably less than the pipe coil and installation labor very much lower.

Historical Evolvement of Coils

Errors were made in the selection of the early blower coils. Pipe coils had usually been selected on the basis of 15°F (9°C) or more temperature difference between room air temperature and the refrigerant temperature inside the coil. Early blower coil selection was more often than not made on this same basis. With forced air circulation over the blower coils in a room, humidities were quite low and blower coils soon earned a bad reputation for excessive dehydration of foods and stored products. Another contributing factor was the fact that packaging of frozen products was also in early status and seals were often neglected. It was the belief of many that forced air circulation in a cold room was always bad for stored products and caused excessive desiccation of the product. It was some time before it was generally recognized that the dehydration of stored products was not primarily caused by air circulation but from the low humidity of the circulated air caused by the relatively high temperature difference between the room temperature and the coil temperature. This high temperature difference resulted in a very cold coil surface which would then tend to condense, or freeze out, the moisture in the air. The dehydrated air would then pick up moisture from the stored products. The answer to this, of course, was the introduction of more coil surface and the raising of the refrigerant temperature to maintain a lesser temperature difference between refrigerant and air. The warmer coil did not dehydrate the air as much as the colder one and the increased surface allowed the air to approach saturation over the coil rather than drying out. It was found that the relative humidity in a cold storage room could be controlled, within limits, by the amount of coil surface and refrigerant temperature variation. Variation in humidity with cold air, particularly in freezers, is far more critical than in higher temperature conditions such as air conditioning since there are far fewer grains of moisture per cubic foot of air at the lowered temperature, even when the air is saturated, than at higher temperatures.

By about 1950 blower coils were rather widely accepted and used in cold storage installations. The temperature difference between room air and refrigerant of about 10°F (5.5°C) was generally used to maintain relative humidities in cooler rooms of about 80%. Temperature differences were then adjusted up or down in the design of an installation to give the desired room humidities. In cooler rooms of 35° to 38°F (2° to 3°C) a range of about 65% to 85% RH can be maintained by varying the refrigerant temperature with relation to the room temperature. Above or below this figure, other means will normally be needed to supplement the refrigeration to obtain the desired results. High humidities are usually obtained by the introduction of steam or atomized water into the air stream. Lowered humidities can be achieved by a very cold coil plus reheating the air so that the room temperature does not go below design conditions. Reheat may be obtained by electrical resistance heaters, hot discharge compressor gas, steam or hot water. Any type of dry heat is normally acceptable. High humidities are usually desirable in both freezer and cooler rooms and for most storage conditions a temperature difference of more than 10°F (5.5°C) between the storage room ambient air temperature and the refrigerant temperature within the coil is not recommended.

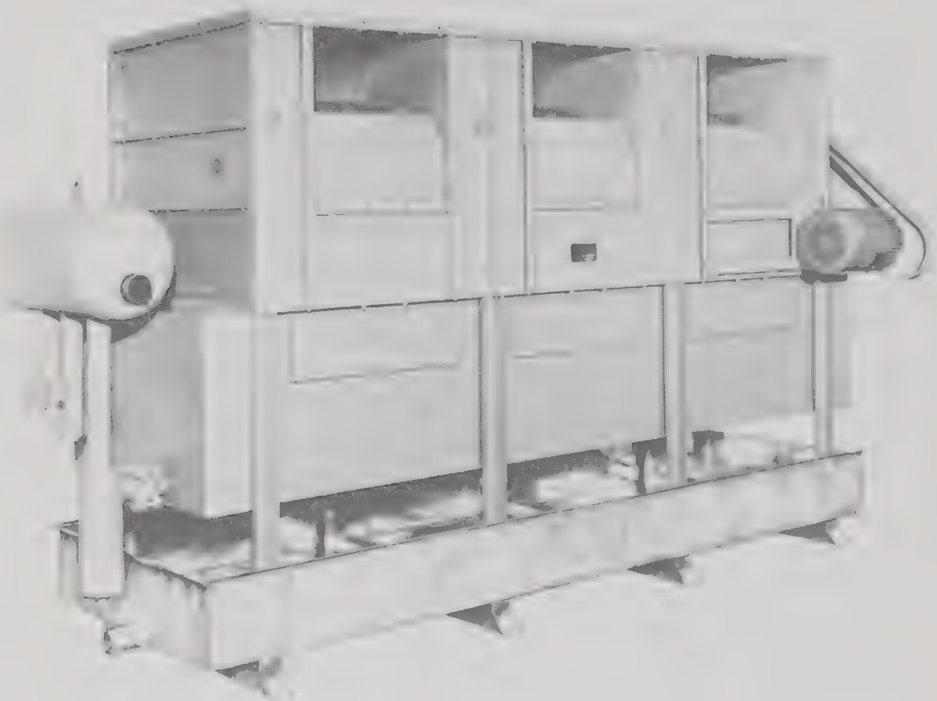
DESIGN FEATURES

The modern cold storage plant can vary from a few thousand square feet floor area to actual acres in size. Rising operating costs and handling expense seem to dictate a minimum cold storage area of 40,000 to 50,000 sq ft (3720 to 4650 m^2) for a break even point, profit wise. This can, of course, vary greatly depending on usage. Private warehouses for warehousing the specific output of a plant can be of almost any size depending on the production capacity of product that feeds them. Ceiling heights will be most often found in the range of 20 to 25 ft (6 to 7.5 m). Construction may vary but usually consists of steel columns and beams and either built up or tilt up exterior walls. Insulation forms an envelope around the room and under the wearing floor. Air or electrically operated doors are normally used in the larger plants. One or more sets of doors are used in a large room depending on the usage and amount of traffic expected. Vestibules with flap doors have been used as a break in air transmission with more or less success and air curtains have and are also used with varying degrees of effectiveness. Door openings are a constant source of maintenance and should be so recognized since large amounts of heat input may be realized through poorly sealed and improperly used doors. It is not believed that any 100% satisfactory door system has thus far been developed. It is therefore essential to get the best out of the existing designs.

Refrigeration equipment in the room normally consists of fan coil units in multiple or singly, depending on the size of the room. The fans are either propeller or centrifugal type depending on whether duct work is used in the room. Quite often ceiling hung units are used, arranged in a pattern to give good air coverage of the cold room without the use of duct work. Some designers will use floor type refrigeration units with short duct risers to carry the air up to ceiling level and discharge it horizontally. Other designers will use a complete duct system. For best conservation of power, duct work should be kept to a minimum. It will usually be found that cold air particularly in a freezer room, will form an even temperature pattern throughout the room regardless of the distribution method used. An intricate air distribution system is not usually a requirement in cold rooms. Good results can be obtained in large rooms by placement of blower units and using them without duct work, except for short stub ducts in the case of floor units, to get air to ceiling level. Various methods of defrost will be discussed in a later chapter.

Fan coil units can be divided roughly into two types; floor mounted and ceiling suspended. The floor unit lends itself well to maintenance and ease of repair but takes up valuable floor space and is also subject to damage from materials handling equipment. Ceiling type units are up and out of the way and are usually used without duct work thus reducing fan power requirements. They are not subject to damage but are subject to neglect unless a very positive maintenance schedule is maintained. Drain lines and refrigerant lines are occasionally subject to pot shots from high forklift truck loads. A third type of installation has also been used with some success. This type is to mount the fan coil unit outside of the room on the roof or outside the walls. This gets the unit completely out of the cold room but is relatively expensive to erect since an insulated small room, or box, must be constructed to hold the unit and some duct work used to get the cold air in and out of the external unit. A number of variations of this type installation are possible.

The design of the rooms will depend somewhat on the proposed use of the facilities. Transit storage in which carloads or truckloads of merchandise are stored for holding and then distributed out of the storage also in complete car or truckloads requires a house with large rooms and good handling facilities for products in bulk and in pallet loads. Location



Courtesy Rigidbilt, Inc.

FIG. 6.3. FLOOR TYPE INDUSTRIAL UNIT COOLER SHOWN WITH ACCUMULATOR FOR AMMONIA SERVICE. MAY BE USED WITH OR WITHOUT DUCTWORK AND CAN BE CONSTRUCTED FOR EITHER COOLER OR FREEZER USE.

usually requires railroad trackage docks as well as truck docks and should be away from heavily congested areas. In fact, modern houses are usually placed in areas where traffic is not too great a problem. To locate in such an area however, is an increasingly difficult problem.

Many warehouses store in many ways. Location is then important so that ideally, local access is readily obtained to docks without heavy traffic congestion. Each storage must be located for the best operation and is a decision that must be made by the owners after intelligent surveys of sites available. It is always well, when possible, to have extra land available if needed. Most warehouses, if at all successful, tend to grow and additions are common. It is therefore essential that space be available for orderly expansion. Advanced planning as to the direction of expansion is a wise precaution to prevent a haphazard placement of rooms and facilities that may be required at a later date and some thought should be given to this at the beginning of the original facility.

STORAGE ROOM CALCULATIONS

There is no exact method of calculating the losses from a cold storage room. Many tables and sample calculations can be found showing losses down to the last increment; but in the last analysis, the refrigeration required becomes a matter of judgment as well as calculation, on the part of the experienced designer. There are also rules of thumb that are used to a greater or lesser extent by many engineers, not as a final load, but as a guide to the accuracy and reasonableness of the mathematical computations. The offhand statement of load in large freezer rooms as 100 tons per acre of floor space is sometimes not too bad a judgment call of the actual load. Most designers will start out a design by calculating losses from the room through the insulation by the use of known factors available for the various types of insulation. To this they will add product load, electrical load, infiltration and other losses peculiar to the installation being figured. When these calculations are all made, the experienced design engineer will take a long hard look at his calculations then, more often than not, add additional load to the calculations. This factor added to the calculated load is variously known as a "factor of ignorance" by some and as a "safety factor" by others. It actually is a judgment factor of experience gained from previous designs and countless observations of existing facilities compared to the designed facilities so that the resulting total load figure obtained for a room contains good engineering which is made up in part by calculation of known factors and by judgment for variables that defy actual calculation formula.

It would be possible to calculate with exactness the loading of a cold room, design to these losses exactly and obtain the exact design temperature in the cold room—if—the room could be locked and access to the room controlled to the design conditions; if the insulation were perfect and the vapor barrier never pierced; if the outside and inside design temperatures were never exceeded and all other design features and restrictions on the room could be exactly controlled. Unfortunately for the designer, this is never a possibility, nor is there any practical way to even approach these conditions. When an investor or group of investors decide to build a cold storage facility, they expect to receive a reasonable return on their investment. They cannot be expected to turn down storage of merchandise and work a room at a pre-determined rate when it is possible to work it faster and thus move more merchandise and obtain more revenue. It is not the designer's prerogative to force an owner to operate at the design load when other methods of operation present themselves to bring in more revenue and do a better job. It is his responsibility to design a facility that will allow the owner to operate in any way he chooses. There are, of course, limits that must be imposed so that absurd loads are not attempted out of proportion to good practice. In order to avoid misunderstandings, a written summary of design conditions and limitations, mutually agreed to, is quite often a desirable thing. An experienced designer should be able to anticipate unusual loads that may occur and other factors of which the owner may not be aware.

It is good practice, when starting a design for a new cold storage facility, to make the conventional load calculations of insulation losses and other losses that may occur in the conventional use of the rooms. These calculations will give an excellent starting figure for the final load determination. In addition to this, there are a number of items that need to be considered in addition to the standard calculated load.

INSULATION AND VAPOR BARRIER FAULTS

Most insulating materials will do an acceptable job when properly installed with a good vapor barrier or when the material forms its own vapor barrier. Over the years, however, some deterioration will most assuredly occur. This can be more or less serious depending on the type of insulation used and the care with which it and any vapor seal used is applied. Insulation "diseases" are insidious and normally grow very slowly. Because deterioration may be very slow, serious damage may result before it is realized there are insulation problems. It is not easy to be sure the insulation in a cold room is holding up the way it should. A very gradual increase in difficulty in maintaining temperature over a period of a few months may be a sign of insulation deterioration providing undue loading has not been added to the room load. More frequent defrosting to maintain clean coils can also be a sign of moisture entrance through vapor barrier leaks. Repairs to insulation are difficult to make since it is difficult to reach some areas after building construction is completed. Load calculations should take into account that there is bound to be some deterioration of insulation and vapor seal over the years no matter how carefully erected. Increase of refrigeration tonnage to compensate for insulation deterioration is not a substitute for insulation maintenance but a safeguard. Maintenance and repair of insulation is important whether the equipment can hold against it or not.

Door Openings

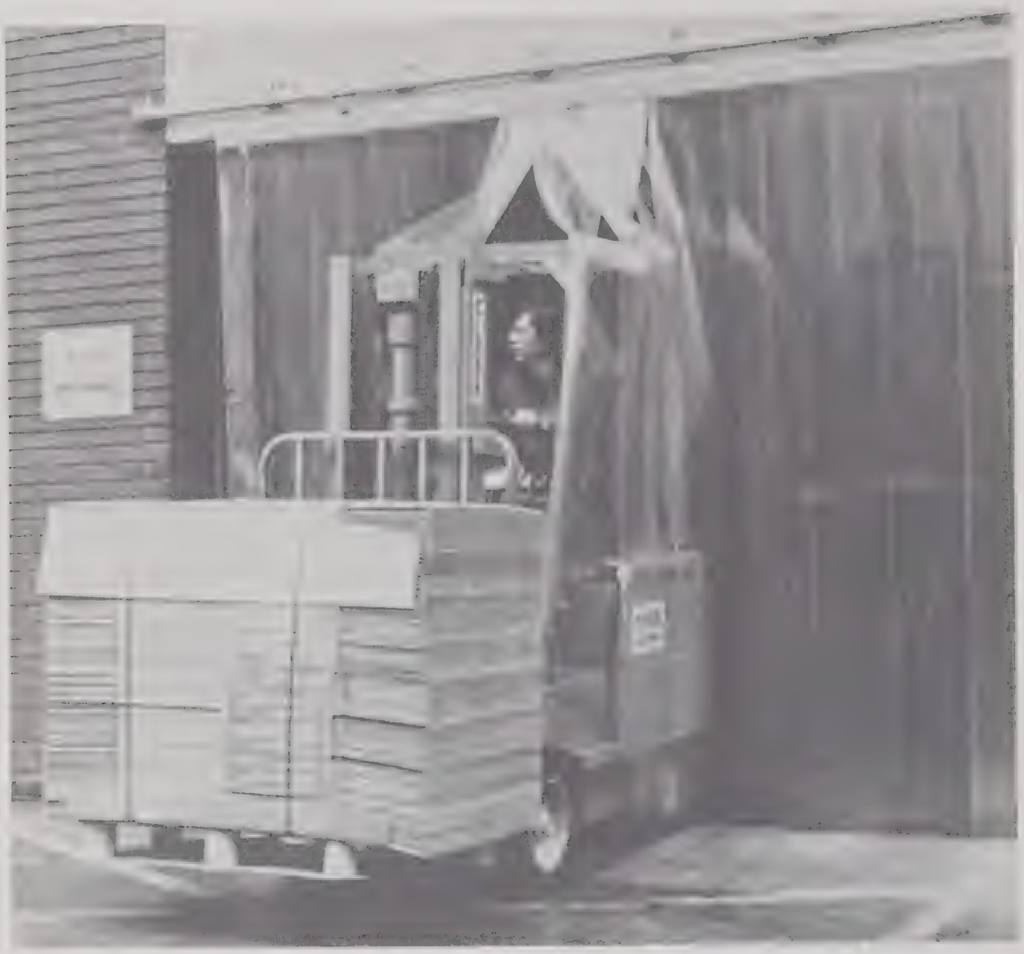
In a successful cold storage operation, business keeps on increasing and operation in and out of cold rooms becomes rather hectic. One result of this is that doors into cold rooms tend to be left open for longer periods. It is difficult to speculate on the amount of heat and moisture that can enter a room through an open door because conditions vary almost constantly. Any one who has observed an open freezer door with the attendant rolling out of fog can testify to the fact that there is a considerable exchange since the cold air coming out must be replaced by warmer air going back in through the upper part of the opening. These losses can be substantial and in some instances, may be the dominant load on a room during certain periods of heavy traffic. Moisture laden air entering the room can also cause more frequent defrost periods to rid coils of excess frost.

It is sometimes difficult to determine whether frequent defrost is occasioned by moisture infiltration through breaks in vapor seals or by entrance during working of the room. Observation of the frequency of defrost necessary during room use vs defrost when rooms are closed such as on a week end, will help determine if the frost is caused all or in part by infiltration of door openings.

Many installations add flap, or swinging doors, to the regular heavy insulated doors. A set of double flap doors with vestibule can effect savings in infiltrated air but are a source of more or less constant maintenance and do slow down operations somewhat. Some promise has been shown by the use of plastic strip closures which are clear heavy plastic and seem to curtail air movement to a considerable extent. In a large room, the actual heat loss through the door insulation or even a non insulated door is insignificant compared to the total insulation losses. The migration of warm air is the cause of heavy loading.

Product Load

Some product load will exist in almost any cold room. Product is sometimes received partially thawed for freezer storage and also warmed up when put in coolers. Adequate tonnage needs to be calculated for each room so that these loads will not unduly effect the room temperature. Sometimes also, products from sharp or blast freezers may be transferred to freezer storage before they are completely frozen to the room temperature and this must be completed in the holding freezer. While this is not considered good practice, it sometimes becomes necessary and adequate capacity should be included in the room refrigeration coils to accomplish this. There could even be times when unfrozen merchandise such as meat carcasses or other meat products are placed in a holding freezer to freeze. Again, this is not good practice and does not produce the best end product but may be used at times and some provision should be made for this.



Courtesy Clark Door Company, Inc.

FIG. 6.4. PLASTIC STRIP DOOR. PLASTIC STRIPS HANG VERTICALLY IN DOOR FRAME AND ARE PUSHED ASIDE BY TRAFFIC THROUGH DOOR.

Unusual loads that occur from time to time do not usually all occur simultaneously so that there is a diversity of loading in a cold storage warehouse. This means that rooms are normally coiled to a heavier total tonnage than the actual machine capacity since loads will shift among different rooms of the facility and it would be almost impossible that all of the rooms would be under maximum conditions at the same time.

Outside Conditions

Most cold storage plant designs are based on outside weather data gathered by the weather bureau over many years. Consideration should be given to that hot spell that is only encountered once in five or six years

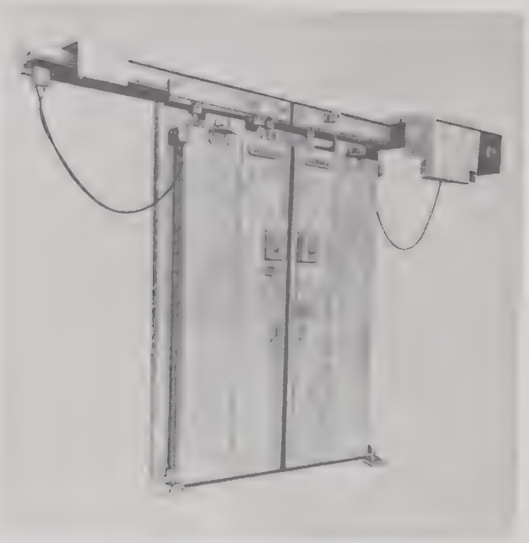


FIG. 6.5. ELECTRICALLY OPERATED BI-PARTING INSULATED COLD STORAGE DOOR. NORMALLY OPERATED BY PULL CORD LOCATED IN TRAFFIC LANE.

Courtesy Jamison Door Company

where temperatures exceed the design temperatures for an extended period. There are a considerable number of tables giving tonnages for cold rooms which are based on theoretical outside temperatures plus some practical loads. Because of the many variables that do exist in the cold storage warehouse business, it is impossible to produce tables of significant accuracy for all conditions. Each room is an entity in itself and should be designed to give a good account regardless of conditions imposed on it. It is always well to keep in mind that it is difficult to put too much refrigeration equipment in a room. Oversized cooling coils can overcome a multitude of design deficiencies.

DESIGN BY EXPERIENCE

It can be seen that design of a cold storage facility is quite often a matter of experience. It should always be remembered that plants are erected to make a reasonable return to the owner on his investment. When designs are inadequate and rooms cannot be used to their full potential; and sometimes a little more, then the owner is not getting a full return. A plant cannot afford to turn away business that could have been handled profitably if just a little more equipment had been installed at the start. It should be the aim of the competent design engineer to design for the ultimate load that can be profitably handled. This goal produced a good plant and a satisfied owner.

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7

Underground Cooler and Freezer Storage

INTRODUCTION

Underground cold storage is as ancient as reasoning Mankind. Wherever mountain caverns existed or where ice was found in nature during some parts of the year, caves, man made or natural, were utilized to some degree of proficiency for preserving food by low temperature. These isolated caverns used for perishable food storage were most generally used by a few tribal or family associates and were not for public participation. Caves were also used by the ancients as a place of residence as they afforded a measure of protection from outside predators of which there were many. In more recent times, many caves throughout the world have been used as tourist attractions with regular tours descending into marked and lighted trails within the natural caves. The most notable recent progress in underground cold storage in North America for large perishable foodstuff tonnages has been that in Eastern Kansas, primarily in the Kansas City area. This area has shown great advancement in the art of storage and other uses of caves since World War II.

The initial commercial cooler and freezer storages to be established dates to World War II in the vicinity of Atchison, Kansas. From various refrigeration files of that period, and especially the magazine, Ice and Refrigeration, of Chicago, Illinois, it is recorded that Lt. Col. Ralph M. Ohmstead, Deputy Director of the War Food Administration Office of Distribution, conceived the idea of utilizing the limestone underground quarry chambers as refrigerated vaults for the millions of pounds of perishable products to be distributed across the United States under the War Food Administration. In effect, to put the mined out chambers to a "secondary use."

The Atchison quarries had about 300 underground "rooms" or bays that averaged 65 ft (20m) square and 13½ ft (4m) high and were well drained and that maintained an average temperature of 55°F (13°C).

Historically, caverns and mine rooms in France, Pennsylvania and Minnesota had been employed for Roquefort cheese aging and subsequent storage. They had been used to store successfully this type of cheese for as long as 3 or 4 months at temperatures near 47°F (8°C). Ohmstead was also familiar with the western desert ice caverns that the pioneers had used to store food, especially during the gold seeking migrations.

The estimated space available in the Atchison limestone mine was 12,000,000 cu ft of piling space. This capacity could accommodate 3000 carloads of foodstuffs. The original limestone mine had a relatively level floor and the Government proceeded to apply a concrete leveling surface. When completed, there were 521,000 sq ft (48.400 m^2) of gross floor area of which 60% could be used for storage. The initial Atchison warehouse equipped for refrigerated storage had a refrigeration system powered by three 250 ton ammonia compressors. Chilled brine was circulated to the various cooling units.

It was estimated that 10 ft (3m) of dried out limestone would be the equivalent of 6 in (15 cm) of corkboard insulation. The original loading was to lower the temperatures and the moisture content of the great mass of stone in the overburden, the walls and the floors. In the pulling down operation, all 750 tons of refrigeration could be used. It was anticipated that after 4 or 5 months of pull down, one 250 ton compressor could maintain the proper temperatures.

At the end of World War II, quarrying was initiated by Lorin Quarries Company at Loring, Kansas, to provide ballast for the Union Pacific tracks. Later, great quantities of crushed rock were used as aggregate in the construction of the Kansas Turnpike and for general building construction in the Kansas City area. Quarrying was at first done by open strip mining but the unusable overburden became so thick that it was not considered economical to continue open mining, and thus tunneling operations were started.

By 1952, further mining had progressed some distance into the bluff. A railroad spur with a capacity of 12 cars was constructed into the mined area. Concrete docks and floors were poured to improve product movement and concrete block walls were built between supporting rock pillars to form rooms. The rock pillars were usually on about 50 to 60 ft (15.5 to 18 m) centers and each pillar was approximately 12 ft (3.5 m) square. Brine ammonia refrigeration equipment was installed to make cooler rooms and two rooms were set aside to be maintained at 0°F (–18°C). About 1956, a second spur track with a capacity of 24 cars was brought into the area. Additional cooler rooms, a second engine room, and one new freezer storage room were developed. The total developed refrigerated area at completion of this work by Natural Storage, Inc., was approximately 750,000 sq ft (69.675 m^2).

In 1961, Southeastern Public Service Company of Kansas City acquired the property and changed the name to Mid-Continent Underground Storage and added freezer space to bring the total developed area to approximately 1,000,000 sq ft (93,000 m^2).

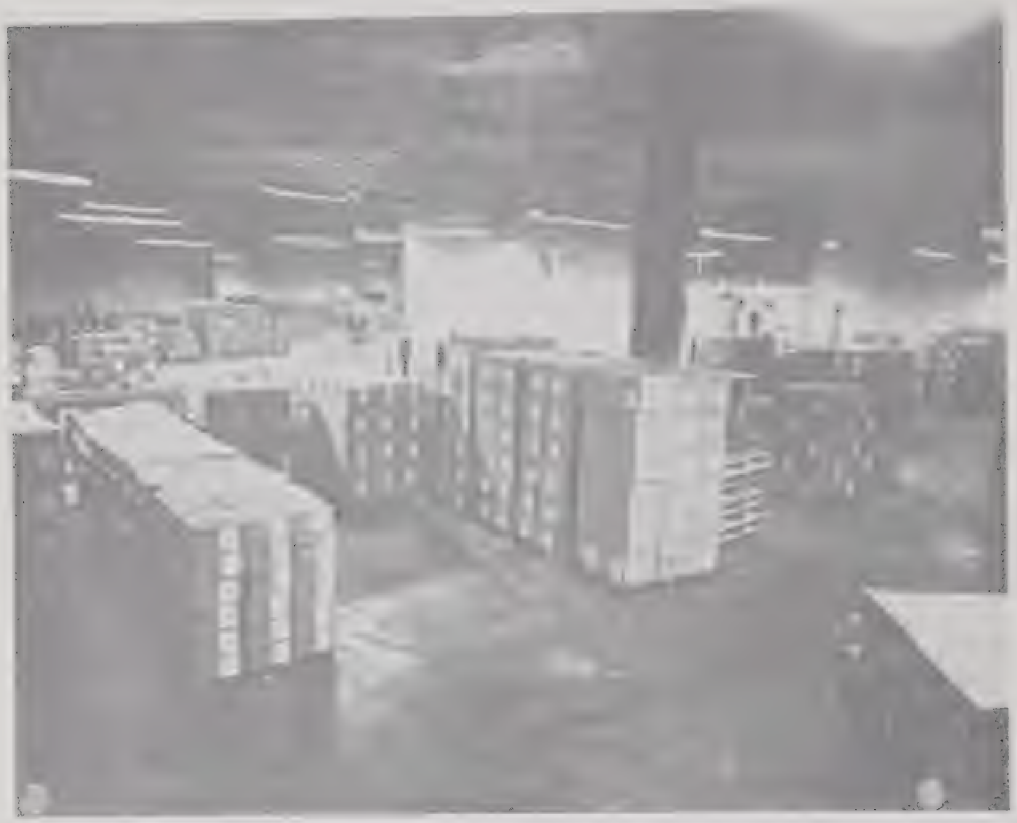
The Inland Cold Storage Company was set up about 1964 and began developing refrigerated space in their quarry in Kansas City, Kansas. The mine rooms and connecting passages were high enough above any possible flood water to insure adequate gravity drainage. While internally there existed a few roof faults that provided nuisance seasonal drips, and at some sections running springs prevailed, these presented no problems that could not be solved by natural drainage. The overburden consisted mostly of several feet of horizontal rock strata capped with an accumulation of pasture soils of humus, clay and sand of varying depths.

In the Kansas City area there have been developments of industrial space, office space and dry storage in the underground space left from the mining operation.

DESIGN AND PERFORMANCE FACTORS IN UNDERGROUND COLD STORAGE

Mr. John G. Mueller, Vice President of Engineering of the Southeastern Public Service Company, reports that "from my personal experience, when we developed the freezer space in 1961, we found that it took a little over 30 days to pull the moisture out of the rock before we were able to bring the room temperature down to a point where frost would form on coils and defrosting became necessary. For 30 days our 23 ten ton blower units were pulling moisture out of the air and rock at a rate of nearly 100 gallons per day, each. After temperature dropped to frost developing conditions, each unit continued to pull out around 50 gallons of water per day. Three years later one 115 ton booster compressor and three of the 10-ton blower units were taken out and transferred to another plant. The room is now being held with 1 ton refrigeration per 1500 to 1700 sq ft (140 to 160 m^2) of refrigerated area. Today we have installed approximately 800 tons of second stage equipment in the entire plant; however, our normal operation requires only a little over 500 tons."

Different mechanical compression systems have been tried in these underground plants including ammonia 2-stage brine cooling units chilling air for the freezer rooms with both rotary and reciprocating compressors; 2-stage air cooled R 12 systems with direct expansion freezer room coils; single stage air cooled R 12 compressors with direct expansion freezer room coils and 3-stage centrifugal compressors with mechanical pumps for recirculation to the freezer room coils.



Courtesy of Southeastern Public Service Co.

FIG. 7.1. UNDERGROUND STORAGE FACILITY.

Mr. James L. Williams reports by letter to the authors: "Ten years of experience with various types of refrigeration systems has proved that an ammonia-brine system provides the best type of refrigeration system to be used in underground freezer storage rooms. This type of system is no more expensive to install than any of the other systems mentioned and has proved to be far more reliable from an operating standpoint. Maintenance costs on an ammonia-brine system are far less than any system installed thus far which has used Freon as a refrigerant. So much of the design work differs so radically from that which would apply to conventional above ground installations that many of the old and accepted rules of thumb have to be discarded. No insulation is used on the floor or the ceiling and after a period of years the freezing point has penetrated back into the rock an approximate distance of 28 ft (8.5m). During the pull down to a subzero temperature the ceiling height is reduced up to 1 in. (2.5cm). Whether or not the floor rises or the ceiling comes down, I don't know, but we know that expansion joints should be provided in the floor around all the pillars as well as around the rock walls making up the periphery of the room. Various roadways have been built inside these underground warehouses to provide ingress and egress for trucks and the various inside truck loading docks have been built for loading and unloading trucks. Railroad spurs have been run into these caves for food express cars. They accommodate many railway cars at both Inland and Mid-Continent underground warehouses."

The excavated limestone strata in both installations is surprisingly level and horizontal in formation and the removed portion was usually 14 to 16 ft (4.25 to 5 m) in height. Internally these tunnels and excavated rooms were supported by the original rock pillars varying in size up to 25 × 25 ft (7.5m) in cross section. The rooms were of varying sizes, usually above 40 ft (12m) square. These rooms had been excavated per instructions of the State and Federal mining authorities to assure adequate safety against cave-ins to the excavators.

This section of Kansas is subject to widespread river flooding. The excavated rock strata were high enough above the river flood water and internally they had only a few roof faults and water springs. Since considerable time had elapsed since excavation ceased, the rooms were filled with damp air caused by the annual thermal variations of the ambient air in the many tunnels. The moisture had also penetrated to some distance into the exposed rock strata. The ceiling required bolstering-up with $\frac{7}{8}$ in. (2.22cm) support rods extended up into the ceiling rock strata for several feet with expansion shields for holding.

In commissioning an old quarry for conversion to underground storage space the factors that must be considered are: (a) adequacy of the support pillars against any collapse of ceiling structure; (b) general safety of the underground area; (c) the mean ground temperature of the region; (d) drainage and seepage possibilities; (e) mean specific heat and mass of the surrounding media; (f) the insulating and heat conductivity value of the earth mass envelope; and (g) the floor and ceiling condition throughout the excavation.

The mean ground temperature in any area and below 20 ft (6m) surface level will correspond within 2 or 3°F (1 or 1.7°C) to ground water temperature of that location. A table of established deep well ground water temperatures for several cities in the United States is given in this chapter. With recent heavy usage of water by urban areas and industry, these tables may not hold absolutely as water tables have dropped alarmingly in some areas.

Table of Mean Underground Water Temperatures

°C	°F	
7	45	for Minneapolis, Minn.
13	56	for Kansas City, Kansas
18	65	for Dallas, Texas
21	70	for Austin, Texas
15	59	for Nashville, Tenn.
13	55	for Columbus, Ohio
12	53	for Lincoln, Nebraska
7	45	for Augusta, Maine
11	52	for Salem, Oregon

Underground Freezer Floors

Floor insulation cannot really be justified in underground cold storage. After a period of time, the rock itself becomes an isulator in that about 10 ft (3m) of rock is considered equivalent to about 6 in (15 cm) of corkboard and as the gradient between natural rock temperature and freezer temperatures is lengthened, the insulating value of the rock under the floor is enhanced. The difference, therefore, is not so much operation as length of time to pull down to temperature and stabilize. Floor treatment usually consists of leveling with a concrete surface. Incidentally, a water vapor proof concrete surface should not be used in leveling the floors. It is necessary that moisture in the form of vapor be allowed to migrate through the concrete and to the cold coils from the rock strata. Otherwise, severe floor damage could result from the building of ice lenses beneath a vapor proof floor surface. Fortunately, most man-made caves have maintained a relatively level floor surface that can be utilized for traffic with a minimum of surfacing treatment.

Underground Cold Storage Ceilings and Walls

Generally speaking, the same argument on insulator is as valid for ceilings and cave walls as it is for floors and walls and ceilings are not normally insulated except masonry partitions between rooms of different temperatures. It should be noted that once the great mass of rock and soil surrounding the underground storage is cooled down to a stabilized temperature, there is a vast flywheel effect established. This flywheel can be of great value in times of mechanical troubles with refrigeration equipment. In an underground storage that has been brought down to temperature and stabilized over a long period, it could be predicted that temperatures would not rise alarmingly even if refrigeration were shut off for several days. It is predicted that a slight bounce of two or three degrees might be experienced in a short time and after that the warm up would be very slow and almost imperceptible on a daily basis. This flywheel effect provides a large margin of safety to a plant. The absence of insulation allows free sublimation of any moisture to the cold coil surfaces from all surfaces of the freezer or cooler.

It may be anticipated that there may be some heaving of the earth's surface due to frost build up or structural changes within the earth itself. Provision should be made in door installations for adequate adjustment from time to time to offset any earth changes.

Doors leading in and out of underground storages need to be planned for the most efficient use of materials handling. Trucks and cars may be routed inside the underground to facilitate loading and unloading. In large cooler and freezer complexes, the insulation of the doors is of secondary importance. Their ability to stop air flow in and out of the cooled portions is important. Several types of bi-parting and flap doors are in use. Plastic strip doors are also worth considering as these have now been developed to a point of practicability even for freezer storage rooms.

Offices, lunchrooms and other areas requiring warmth will need to be heated to obtain comfortable conditions.

Caves excavated for construction stone products in lime rock or coal mines with fully excavated rooms on a mountainside may be commercially feasible developments for freezer and cooler rooms and also for other non-refrigerated uses. It would be important that the mining operations had been accomplished to leave a safe underground area with adequate support pillars and a roof structure that was sound. Commercial refrigeration compressors and related equipment should be used as a source of mechanical cold for refrigerated areas. As a workable storage structure, the main entrance to such caves, or rooms, should be level ground, and inside, the roadway should be inclined to the main outside entrance for assured continuous drainage. The natural structure should preferably be a horizontal strata of limestone or dense slate, and all roof strata should be free of appreciable water leakage or pockets. In freezers, the ceiling and floor will eventually attain temperature below freezing and there could be some frost heaving and this should be anticipated. Each prospective underground storage room should receive adequate engineering inspection to assure that the floors are adequately drained and the ceiling well supported by tension rods to support any imbalance of stresses with temperature changes and locally provided excess vibrations.

Energy Conservation in Underground Storage Operations

Underground cold storage operations can probably provide some energy savings over the above ground storage. However, these savings may not be as great as might be imagined. Storage operations in freezer areas have shown that about three times the square feet may be refrigerated by a ton of refrigeration in an underground storage as in one above ground. To offset this, many underground storages are limited to ceiling heights of 13 or 14 ft (4 or 4.25 m) versus 20 to 25 ft (6 to 7.5 m) in above ground facilities. Pillars also eat up a considerable portion of the space so that instead of a 3 to 1 advantage, there probably is only a small advantage energy wise in utilization of underground storages. Handling of product is also somewhat more troublesome due to longer hauls per ton of merchandise handled. More labor may also be required. In starting a new room, the pull down time is much longer in the underground storage than an above ground facility. As mentioned before, the plus side of this coin is the tremendous flywheel safety factor of the underground facility in case of mechanical failure.

In areas where cave ceiling heights may be somewhat higher and allow higher stacking of merchandise, greater energy savings may accrue in refrigerating underground storages. It would seem that in any event, there are some savings to be made in first cost of construction of facilities and a possibility of some energy savings in the performance of the storage after the initial pull-down and stabilization to desired temperature. Also it is probable that various thicknesses of overburden as well as the character of the soil and other variables could show differences in energy consumed per unit area of floor space.

Underground storage has now been used successfully for quite a number of years and is feasible where the underground space is available in a condition where it can be prepared properly and with proper drainage facilities. It would be recommended that, before beginning any such project, the conditions and facilities be studied by someone familiar with this type of storage and due attention given to any advice before final commitments are made.

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8

Insulation for Cold Storage Installations

Heat transfer is a rather complex process. Heat may be transferred by conductivity, radiation and convection. In thermal insulation of cold rooms, the main concern is with thermal conduction of heat from the warm side into the cold room. In some northern climates this may be reversed in the case of cooler rooms when outside temperatures fall to levels below the cooler temperatures, in which case the insulation acts to retain heat (relatively) within the room rather than preventing it from entering. Materials of high density such as metals, etc., transfer heat readily. Materials of low density such as fiberglass, cork and other materials in which the molecules are far apart usually have a retardent effect on the transfer of heat and may be used as insulants.

HEAT INSULATORS

"Dead air space" is an excellent insulation against heat transfer. Unfortunately, however, "dead air" space to be effective, must be truly "dead" in that there is no flow of air or air currents. Since this condition is virtually impossible to achieve in building construction, the next best thing is to fill the insulating space with very small, lightweight, cellular units. These cellular units are made up of millions of small air spaces with fibrous walls. These air spaces are so small that they prevent air movement and approach most nearly the idea of dead air space for insulation.

Requirements of Good Insulation

Good insulating materials have several desirable characteristics which are common to all good insulants. These are: (1) low conductivity; (2) good handling characteristics; (3) resistance to decay, deterioration and odor absorption; (4) lightness to lower weight in construction design; (5) ability to retain dimensions; (6) resistance to moisture; and (7) nonflammable characteristics.

Low Conductivity

Conductivity is expressed as the number of British thermal units that will pass through a piece of material 1 sq ft in area over a period of one hour for each degree Fahrenheit difference in temperature of the two faces 1 inch apart. This factor should be low for a good insulation since thickness can be a factor to obtain the desired resistance to heat flow. Conductivity is raised by an increase in moisture content of the insulation. Loose fill insulations probably present the most difficult moisture (vapor) barrier problems. In passing judgment on any insulation material, thickness required for low heat flow as well as permanency and cost per unit of area should be considered.

Good Handling Characteristics

Many insulating materials are relatively hard to handle and application cost is high. Rather elaborate installation procedures are necessary for fill insulations which may raise the ultimate price higher than a more expensive insulation. Rigid insulation is relatively easy to apply. Sprayed on or foamed insulations also are applied without too much special preparation. In deciding on the type of insulation to use, the total cost of the insulation well applied should, of course, always be figured. Although rigid insulation is relatively easy to apply, care should be taken that corners are not broken or other damage done, since these imperfections can cause future troubles. In considering any insulation material, the ease of handling, resistance to damaging and permanency should always be factors in the final choice.

Resistance to Decay, Deterioration and Odor Absorption

The installation of a good insulation blanket requires considerable labor and expense. The first cost, maintenance and repair costs must all be considered in the over all expensing of the job. Insulants used should be of a nature to resist the attacks of vermin and rodents and should be of as permanent a nature as possible against rot and deterioration. By nature of the location of insulation in a cold storage, replacement and extensive repairs are very expensive. The cheapest first cost may not be the cheapest in the long run.

Lightness in Weight

It is fortunate that most of the good insulants are light in weight. This feature means that building structures do not have to be unduly strengthened to support the load of the insulation. When a fill type insulation is used and there is a chance that moisture could enter the insulation or even in some rigid forms not properly sealed, consideration should be given to additional weight of moisture that could condense in the insulation. The possibility of this additional weight should always be considered in the building design if an insulant is used that could become moisture saturated, even though the chance is remote.

Ability to Retain Volume Dimensions

Molded insulations and sprayed on insulations normally have good dimensional stability and will retain their original shape after many years. When not properly sealed however, some insulants may tend to break down and lose their original form.

Many fill insulations may tend to settle with the passage of time and, unless some method of repacking is used, may lose much of their effectiveness. Fill insulations can be used but must be installed with extreme care. Vapor sealing is of the utmost importance when this type of insulation is used.

Resistance to Moisture

Moisture infiltration into insulation can destroy much of its insulating properties. A relatively small amount can reduce the effectiveness of an insulation by a very great amount. Also in freezer applications, infiltrated moisture can freeze and disintegrate the insulating envelope. It is, therefore, highly desirable to use an insulating material that will resist the penetration of moisture.

Nonflammability

Insulants that are flammable should be avoided. Materials that will support combustion are hazardous, particularly during the construction phase of a warehouse and, to a lesser extent after pull down to temperature. A considerable number of refrigerated rooms have been lost during construction due to accidental firing of the insulating material.

FORMS OF INSULATION

Insulations used in cold storage wall and ceiling construction may be classified generally in several categories. The names of the categories are generally self-descriptive of the type insulation. Combinations and borderline characteristics can also be found that may not fit exactly into the general categories given.

Loose Fill Insulation

As the name implies, this type of insulation consists of small granules of an insulant, or random small forms, which are either poured or packed into a pre-prepared space, the barriers being sufficiently strong and rigid to retain the insulation in place. Examples of this type of insulation are ground cork board, mineral wools, and other lightweight materials. In early times sawdust and wood shavings were quite often used to insulate cold rooms. Vapor seal is of great importance in this type insulation. Settling of some of the fill type insulants can also occur.

Semi-rigid Insulation

Semi-rigid insulation consists of insulating material formed into a blanket or batt form. It has no particular strength but can be tacked or stapled onto a surface and the form will retain a fairly good dimensional stability. Sometimes a reflective type insulation may be cemented to one side for further insulating effect. This type of insulation may be formed with fiberglass, or mineral wool and other semi soft materials. It is most often used on storages where temperatures are not in a low range since this type is difficult to seal against moisture. It is also found in residential forms and as air duct insulation. It is not generally used in low temperature insulation work.

Rigid or Board Form Insulation

Insulation in board form is often used in cold storage insulation work and lends itself well to this type of installation. These insulants can be formed from many materials such as cork with binder, fiberglass, polyurethane and other materials. The rigid board forms allow close fitting of the boards to form a tight wall or ceiling which is helpful in any good installation. Some of the materials form part of their own vapor barriers but vapor tight barriers are a necessity since even rigid insulants can be disintegrated in the event moisture can penetrate and freeze. In present day construction, most cooler and freezer rooms make use of the built up type of insulation and will use some type of rigid board.

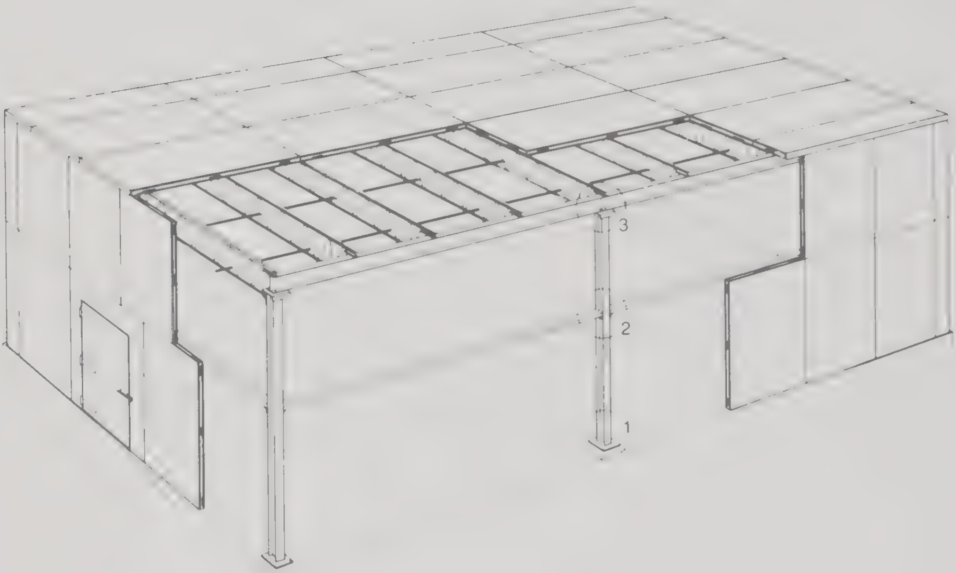
Pre-fabricated Panels

In recent years, the construction of cold storage rooms from pre-fabricated panels has progressed from very small cooler and freezer vaults to the construction of larger and larger rooms. Pre-fabricated insulated panels are formed by placing insulation between finish materials such as metals or other types of hard finishes. In the case of foamed insulations,

REFRIGERATED WAREHOUSES

With Urethane Foamed in Place Insulation

Details of Warehouse Construction



Modular 4″ Foam Panel Construction Provides Economical First Cost.
Available Any Length x Any Width x Heights up to 31′8″. Clear Span Thru 60′-0″.

Courtesy Master-Bilt Products

FIG. 8.1. MODULAR CONSTRUCTION FOR COLD STORAGE ROOMS UTILIZING PREFORMED INSULATED PANELS.

the outside panels are placed in a form or mold and the insulating material is formed by foaming a controlled amount into the spaces between the two surface panels. The finished product thus becomes a sandwich in which the insulation is contained between steel, aluminum or other surface material. By the use of solid sheets on each side of the insulation, an almost perfect vapor seal may be achieved. These panels can be made in a variety of thicknesses and sizes. In this type of construction, there is the problem of vapor sealing where the panels are joined together. This is accomplished in a variety of ways, usually employing some type of formed gasket between the edges of the panels or sealing compounds or a combination of both. Panels are held together by some type of locking device imbedded in the panel structure itself. In large rooms of considerable height, multiple panels are sometimes used or long panels the full height of the room. Panel widths are often about four feet (1.25m) to utilize standard steel or metal roll widths. In the larger structures an interior steel framework is erected and the panels fastened to this steel frame in various ways for both the walls and ceiling. Various interior finishes may be applied to conform to the usage desired. The pre-fabricated panel usually assures a uniform thickness of insulation as well as an excellent vapor seal.

Sprayed on Insulation

Some of the synthetic insulants, such as polyurethane, can be expanded directly on a wall surface by mixing ingredients at a nozzle and blowing the mixture against a wall or ceiling to be insulated. The mixture will adhere to the wall and expand rather rapidly and by control of the spraying process and the number of coats applied, the total thickness of the insulation can be regulated. When sprayed against a clean dry surface this type of insulation forms its own vapor seal. There is one drawback to this type of application. It is very difficult to obtain a uniform thickness and this often results in a rather unattractive room. However, the insulating value is good. In applying this type of insulation, care should be exercised if applying over any other insulation since the spray will form a vapor seal of its own thus rendering any other insulation on the warm side more prone to become moisture logged which, in turn, could force the sprayed on insulation to turn loose under severe conditions.

PROPERTIES OF HEAT INSULATORS

The U. S. Bureau of Standards has done extensive work on the properties of insulators. The present ASHRAE guide also publishes very comprehensive tables listing the properties of various insulation materials.

Positive vapor sealing is a must regardless of the insulating material used. As stated before, some insulants are inherently vapor resistant. Others require complete vapor sealing to prevent infiltration of moisture vapor. Water vapor in air is actually a gas, or low pressure steam, and can penetrate very minute cracks and pinhole sized openings. Once inside in a cold area, this moisture can condense out as water. The moisture vapor can enter a much smaller opening than the condensed water can flow out of and hence, the water may become trapped in the insulation with resultant deterioration over a relatively short period of time. In fill insulations where perfect vapor sealing is almost an impossibility, the vapor barrier is constructed on the outside, or warm side, of the insulation in an endeavor to prohibit the flow of moisture into the insulation. It is well to provide an interior finish that is porous and allow easy egress of any moisture that enters the insulation from the outside.

In this manner, trouble can often be prevented, or postponed by providing any easy path out of the insulation to the cold coil and keeping the insulation relatively dry. Insulation can be completely destroyed by excess moisture infiltration and entrapment.

FIGURING WALL AND CEILING LOSSES THROUGH INSULATION

In figuring heat losses from a cold storage room, the logical starting point is the heat loss through the insulated walls and ceilings. This is customarily done by utilizing the appropriate factor of Btu per sq ft of surface per inch of thickness, correcting to the thickness to be used and multiplying by the proper temperature difference between the inside and outside of the wall at peak conditions. The heat transfer factor may be readily obtained from manufacturers data or from reference or text books on refrigeration. Normally, the wall in a cold storage is made up of more than one item. It may be a concrete wall plus insulation plus an inside wall finish. All of these items have some value as well as the air film resistance at the inside and outside surface. For laboratory testing, it may be necessary to figure the over-all heat transfer factor by combining all of the resistances to heat flow. However, in cold storage insulation where the actual insulation is relatively thick, the single value of "U" factor of the insulation alone far outweighs the other masonry and related items in the wall construction and under most conditions, the value of the insulation factor alone can be used for calculating losses. At best, load calculations are rather inexact and are of necessity tempered with experience.

Taking into account factors that are not particularly significant in the over-all figure is not usually done.

Cold and Heat Transfer Through Walls and Space

In discussing refrigeration and the insulation of refrigerated rooms or buildings, it is of primary interest that a barrier be provided against the heat and moisture traveling into the refrigerated room. One of the basic laws of thermodynamics is that heat always travels from a condition of high temperature to a condition of low temperature. In other words, heat cannot travel up hill. It must always flow from hot to cold. When the outside temperature is higher than the inside temperature of a room, then a thermal barrier must be erected to protect the room against heat and moisture moving inward to the cold rooms. If outside temperature is colder than the inside temperature, then the room must be protected against the outward flow of heat. In many areas where very cold weather is experienced, it is not uncommon to need to protect cold storage rooms against heat flow out of the room during cold weather and a reverse flow during periods of warmer weather.

Hot air can always carry more moisture than cold air. If hot air moves into a cold area, excess moisture which the air, as it cools down, cannot hold will condense out in the form of free water on walls and on the coils of the cold room. If this condensation occurs within the insulation, the insulation may become valueless as an insulant and in extreme cases, almost totally destroyed.

ADEQUATE INSULATION AND PERMANENT VAPOR BARRIERS

In designing cold storage enclosures, the design engineer should be fully aware of the difficulty and seriousness of the proper design and also the dependence on good installation workmanship. A permanent insulation and vapor barrier are on the order of difficult to impossible. This should be recognized in the design and great care also needs to be exercised in the actual building of refrigerated enclosures.

In cold storage rooms, most vapor barriers are installed on the outer wall side to protect the wall from moisture moving into the colder insulation, then condensing. If the outside temperature never drops lower than the inside, then virtually no moisture will travel from the cold room into the insulation and a vapor barrier is not necessary for the cold side of the wall. Fortunately, the amount of moisture per cubic foot of cold storage room air is very small and even if the outside temperature drops lower than that in the cold room, the condensation in the insulation is not too serious.

The significant detail of a refrigerated enclosure is that it should never be without an adequate and properly installed vapor barrier. This is true regardless of the type of insulation used. Some insulants, as mentioned before, form their own vapor barriers while others, such as prefabricated panels, have their own vapor seals but in all instances, a proper vapor seal must exist in one form or another for good operation and adequate protection of the cold room. A vapor barrier, when applied, should be located on the exterior surface of insulated enclosures and on the warm side of partitions having significant temperature differentials. This logic applies where the outside temperatures are normally higher than the interior of the cold storage rooms the majority of the time. Special conditions of arctic location might require different criteria.

The preferred applied vapor barrier material is metallic foil, laminated between layers of protective coverings. Observations in this study have been limited to aluminum metallic foils. Other materials made up of synthetic plastics have also been used successfully as barriers. Mop coats of bitumens should not be considered as vapor barriers. All joints and seams of the vapor barrier should be lapped and sealed by pressure sensitive tape or other approved method. When staples or nails are used to attach vapor barriers, the penetrations should be sealed with pressure sensitive tape.

The installed vapor barrier, with seals, should be of such a design and nature that it can absorb contraction and expansion of 1 inch (2.54 cm) per 100 ft (30.5 m), remain in a resiliant state at operating temperatures, and be resistant to chemical attack. The sealants used should be compatible with the insulation and vapor barrier.

Vapor barriers should be installed completely prior to the application of insulation. The vapor barrier should then be carefully examined by the owners representative to insure that the material is properly installed and sealed. Also at this time, all necessary openings should be prelocated and provision made for their proper sealing. A good vapor barrier, properly installed, will provide many years of economical low-temperature insulated storage with most commercial insulants. The hazard of deterioration due to moisture is greater with organic insulations and organic structural members because of the difficulty of avoiding vapor leaks in a vapor barrier, as well as the nature of organic materials to absorb moisture.

National Academy of Science survey teams found only one type of insulation, cellular glass, free of moisture except on its surface. All other insulating materials were found to contain some moisture. Some of the synthetic foamed insulants are also relatively moisture free since they form many micro air chambers sealed and bonded together.

The average moisture content of the organic-board-insulation core samples is approximately 30% by weight, while the average moisture content of glass fiber core samples was approximately 18% by weight and no moisture was found in the cellular glass insulation.

If a positive vapor seal is installed, most any of the commercial cold storage insulants can be used with success. However, defective vapor barriers can cause havoc with many insulants. Modern practice seems to be to the man-made insulating materials rather than the organic types formerly used. Cork board, once a favorite, has almost disappeared from the market place due to price differential between it and some of the newer insulating materials. Inherently sealed insulants are always an advantage since they lessen the possibility of poor heat characteristics due to moisture infiltration and lend themselves to easier installation.

INSTALLATION FAILURES

Installation failures and weaknesses reveal that many installers do not appreciate the effect of mechanical penetration of the vapor barrier

Uninformed builders and workers have installed equipment hangers, meat racks, sprinkler systems, electric wiring and even refrigerant piping without regard to the risks of penetrating the vapor barrier and cut through this barrier at will even during construction of the barriers. In some cases the metal penetrations were not properly insulated and themselves became notable heat carriers. Failures of an entire wall or ceiling can result from such practice.

Frequent and extensive cracking of exterior walls can be found in some installations. This cracking can be from structural shifting or from mechanical damage from product moving equipment. Obviously, if serious, these cracks and stresses can cause vapor barrier damage. Exterior walls should be repaired promptly when any damage occurs.

Refrigerated Space doors have been found to cause considerable trouble in cold storage operation. Freezing, sagging, rotting of wood parts and extreme physical abuse are all common to the problem. Air operated doors have met with some success but electrically operated bi-parting doors seem to have gained the most favor. Vestibules have been found helpful in freezers to cut down on air losses with air operated swinging doors or bump type doors and more recently plastic strip doors which seem to do a good job in cutting down on air infiltration and to give relatively long life. Any investment is a good one that will cut down on unnecessary air infiltration to a cold room. Careful attention to details and instructions should be given by contractors, or anyone installing doors so that they operate correctly and smoothly.

NIGHT COOLING EFFECTS

Some ceiling, or top floor, insulation failures may be brought about by night cooling (sometimes called interstellar cooling) of the roof at which time the vapor movement may be reversed in the cold storage rooms from inside by a lower temperature on the outside roof than within the rooms. This could occur in cooler rooms, particularly in northern climates. Under recurring low outside roof surface temperatures, the room moisture, even though slight, with pressures reversed will penetrate the insulation from within, unopposed by any vapor barrier. Such moisture can lodge in the insulation with consequent deterioration and increased heat flow through the insulation. Freezer rooms are not as susceptible to this type of damage since in most locations the outside temperature is seldom below the freezer room temperature for extended periods.

Where air spaces occur between weather roofs and insulated space ceilings, they should be kept well ventilated with adequate air movement to prevent condensation occurring from night cooling of this air space. This condensed moisture may act as "rainfall' upon the insulated ceiling with consequent damage to the insulation.

ECONOMICS OF INSULATION INSTALLATIONS

In the installation of insulation, the builder will want to get the best return he can from his investment. The maintenance as well as first cost are factors in purchasing an insulation installation. The thickness of the insulation can be equated to the power cost to maintain temperatures in the vault, charging that part of the cost to the heat loss of the walls and ceilings. Table 8.1 was prepared some years ago giving the economical thickness of insulation for northern and southern parts of the country. This table is now probably obsolete since it was based on refrigeration power costs of the early 1970's which are no longer valid. Power costs have increased and very well may increase considerably above their present levels. Some crystal ball gazing may be necessary to foretell future power costs. Obviously they probably will not get lower. It would, therefore, seem logical to increase thicknesses of insulation over those in the table. It is extremely difficult to predict with any certainty where power costs may go in the years ahead. It does seem more or less certain that they will go up. With this in mind it would appear wise to use as much insulation as is practicable within the cost expenditures allowable for the job. Greater thicknesses of poorer insulation jobs are not economical when compared to carefully controlled well made insulation.

TABLE 8.1. COLD AND FREEZER WAREHOUSES MINIMUM INSULATION THICKNESSES

Storage Temperature		Insulation k = 0.3 Thickness In. (cm)	
°F	°C	Northern US	Southern US
25 to 40	− 4. to + 4.5	4 (10)	5 (13)
15 to 25	− 9.5 to − 4.	5 (13)	6 (15)
0 to 15	−17.7 to − 9.5	6 (15)	7 (18)
0 to −15	−17.7 to −26.1	7 (18)	8 (20)
−15 to −40	−26.1 to −40	9 (23)	10 (25)

FAILURE OBSERVATIONS IN COLD STORAGE WAREHOUSES

In almost all checks, moisture content of ceiling samples of insulation showed higher content than wall samples.

Only a few installations showed high performance over many years. The majority of insulation installation showed some deficiencies within a relatively short time span.

Not too many cases of termite infestation have been observed although there have been isolated instances.

Rodent nesting has been found in organic insulations but no evidence was found of any eating of the insulation.

In the majority of cases when galvanized metals were used in cold storage rooms, particularly light fixtures, corrosion was occurring.

The exteriors of refrigerated structures have proved surprisingly porous. Operational difficulties are more apparent on the windward side of a building. In some cases the addition of breakdown areas and similar enclosures on the windward side have materially reduced refrigeration difficulties.

Wood beams have usually been found to be in poor condition. Wood has been found warped, buckled, shrunken, bulged, and in a few cases, termite infested. Wood used with reflective insulation in freezer rooms has often been in good condition. Heart redwood, tidewater cyprus, and pressure treated woods appear to be least liable to deterioration.

Numerous serious floor heaving problems have been observed under freezers. Correction can be achieved by the removal and leveling of the floor and the installation of heating ducts or heating pipes beneath the floor before re-insulating the floor to prevent freezing conditions from starting under an insulated floor.

TABLE 8.2. INSULATING SLABS OR BOARDS

Material	Density Lb per Cu Ft	Kg/m^3	Average Btu Passing per Hr Through a Plate of Material 1 Sq Ft in Area, 1 In. Thick, per °F Difference in the Two Faces	Kcal per Hr per m^2 per °C Thickness-2.54 cm
Cellular glass	9	144.2	0.41	2.00
Glass fiber	7	112.1	0.21	1.02
Polyurethane (exp.)	3	48.1	0.17	.83
Rubber (exp.)	4.5	72.1	0.22	1.07
Polystyrene (extruded)	1.9	30.4	0.22	1.07
Expounded polystyrene	1.0	16.0	0.24	1.17

GENERAL SUGGESTIONS ON INSULATION

Nonhygroscopic insulations of inorganic or plastic materials, board or batt type, should be used for both freezer and cooler insulation. Insulants of polyurethane composition applied in a controlled condition such as board form seem to be gaining in popularity as well as other inorganic compounds that can be manufactured in board form.

Natural organic hygroscopic insulants will absorb some moisture and their transfer factor should take into account this fact. Loose fill insulations are used but extreme care should be used in their installation.

The owner's inspector should be experienced in insulation application technique. Inspections need to be thorough since failure to install correctly can be very costly in future maintenance and repair.

Stored insulation should be well protected from the weather and also from possible mechanical damage. Rigid insulation should also be handled with care to prevent breakage of board when installing with the consequent breakdown while in use.

Ceiling areas above insulated ceilings should be well ventilated to prevent condensation of moisture and consequent deterioration from occurring on top of the insulation.

TABLE 8.3. HEAT GAIN FACTORS (WALLS, FLOOR AND CEILINGS) BTU PER SQ FT (24 HR) COLD STORAGE WAREHOUSES

Insulation k = 0.3		Temp Difference (Ambient Temp Minus Storage Temp), °F									Kcal/m²/24 Hrs
Thickness In.	cm	1	40	50	60	70	80	90	100	110	per 1°C
4	10.16	1.8	72	90	108	126	144	162	180	216	8.78
6	15.24	1.2	48	60	72	84	96	108	120	132	5.86
8	20.32	0.90	36	45	54	63	72	81	90	99	4.89
10	24.40	0.72	29	36	43	50	58	65	72	79	3.51
12	30.48	0.60	24	30	36	42	48	54	60	66	2.93

Start Up

The initial pull down in temperature is important in any cold storage room and particularly in freezer rooms. Pull down should be slow and in the case of freezers should be held just above the freezing point for some time to draw any entrapped moisture out of the insulation and other parts of the structure. This may take several days depending on the structure and type of insulation used. Pull down below freezing should be relatively slow until final temperature is reached. The room, preferably, should be held at the design temperature for several days before loading with merchandise.

CODES

Local building and fire codes should be checked prior to a final decision on the insulation type to be used. Some variance will be found in codes in different cities. In some areas, it may be found that no particular code exists. In other areas rather restrictive codes as to what can be used may be found. It is well to check this out at the start of any project so that insulation types used are compatible with the local situation.

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9

The Insulation of Freezer and Cooler Warehouse Floors

The advent of the modern cold storage plant built entirely on one level brings on some problems in the realm of floor insulation, particularly with floors directly on grade. In view of rising energy costs and conservation of energy as well as financial aspects of floor costs, it is well to take a good look at floor problems from all angles. One solution of the problem is the floor placed directly on grade with no commercial insulation; utilizing the insulating effect of the earth itself. This solution has some attendant problems that need to be taken into account before decisions are made. A rather good case both for and against the non-insulated floor can be constructed. The other solution also has certain problems that must be understood and worked out to assure long time service.

Unfortunately, there is no pat answer to the floor problem. Each location has considerable geological complexity that must be considered to the best of the designers ability before construction of a warehouse is started. Certain risks attend the use of non-insulated floors and the prospective owner should be aware of these before making a decision. The final analysis of the problem lies with the individual warehouse location and good judgment of the design engineer. The arguments following are some of the items that have been observed over the years.

DEFINITION

Before any discussion, it is well to define a "non-insulated" floor. In the context of this chapter, a non-insulated freezer or cooler floor may be defined as a floor surface, usually concrete, resting directly on grade or fill with no commercial grade insulation installed as a barrier to the flow of heat, but utilizing the insulating effect of the soil beneath the floor as a heat barrier. In no instance does the term "noninsulated" in this chapter mean a floor of concrete or other structural material over a void. With this in mind, it becomes evident that the discussion of non-insulated floors is actually a discussion relating to the value of the soil or fill beneath the floor as an insulant without the addition of commercial insulants. Soil characteristics can have infinite variations and so the reaction of soils to cold temperatures can have infinite variations. Each physical location of a freezer floor presents different problems, sometimes within a single complex of freezer rooms. Unfortunately, the divergent views and the complexity of the problem do not lend themselves to a simple solution and the final decision is usually an educated guess based on experience and some knowledge of the earth structure beneath the proposed freezer rooms.

All types of soil have some insulating value. In some common soils, between 2 and 3 feet thickness may be equivalent to 1 inch of good commercial insulation. Thus, within limits, there is good insulating value in a "non-insulated" floor if the ground beneath the floor is taken into consideration. The actual insulating value of soil can vary widely depending on the soil structure, distance to free water, and other factors. In dry areas, after a floor has stabilized itself temperature wise, the losses through the floor will approximate the losses through about 6 in (15.25 cm) of good commercial insulation with a U factor of about .045 Btu per sq ft per deg. F. This will be an average figure since losses will vary throughout the room. Around the perimeter of the room there will be high losses to the adjacent warm areas unless a band of insulation is extended into the room or trenched down from the wall. Non-insulated floors tend to lend themselves to large areas rather than small rooms. If small rooms are to be used without floor insulation, it is almost mandatory that a band of insulation be used around the perimeter of the room either extending into the room 2 or 3 ft (.6 or .9m) or extending down below the walls to break the flow of heat in from warm adjacent spaces. It is questionable whether small rooms without floor insulation for freezer temperatures can be justified. In considering floor insulation for large areas purely from the standpoint of heat flow, it is doubtful that the cost of commercial insulation can ever be justified. There are, however, other considerations that may justify insulation even though the first cost is high. These will be discussed later on in this chapter.

HEATING UNDER NON-INSULATED FLOORS

Experience has dictated that some method of heating beneath a non-insulated floor is desirable. In a freezer room over an extended period of time, the temperature of the soil beneath the floor will fall gradually and the freezing line will deepen with time. Observations of such a freezer over a period of years indicated the freezing line was at a depth greater than 35 ft (11m), the deepest point of measurement. Observed temperatures indicated the freezing line is progressive although at an apparently slowing rate as the freezing line becomes deeper. It should be assumed that the total depth will vary depending on soil structure, moisture of the ground, depth of water tables and other factors. Very little factual data is available but the following hypothesis seems reasonable in the light of observation of floors over a number of years. As the depth of the freezing line lowers, ice lenses can and do form but not always at the same rate or thickness. Various types of soil will apparently change the time interval in forming ice lenses; also the depth of the lenses formed. As ice lenses form, they tend to block off the migration of moisture from the ground to the cooling coil by stopping the moisture at the lens. This in turn, causes a thicker lens to form and this continued expansion of the ice lens will eventually cause the floor to heave. There are apparently no known rules to predict floor heavage. It would seem that only minor differences in soil structure can cause or retard heavage. Large adjacent rooms in close proximity do not always show the same heaving characteristics. In areas where subsurface moisture is high, floor heaving would be expected in a relatively short time while in relatively dry areas, it may not occur for years and with a combination of highly porous dry soil and porous floor sufrace, it is possible it might never occur. The problem of floors is that the condition of the soil under the freezer floor can change; sometimes with the seasons of the year and at other times as a result of changes made by building or excavations nearby. For this reason, it is almost impossible to formulate any hard and fast rules. The ideal freezer non-insulated floor would consist of a porous wearing floor (no moisture barrier) with a porous soil substructure in a relatively dry area so that any moisture arising from the soil could pass readily up through the soil and through the wearing floor to the room refrigeration coils where it would condense as ice or frost on the cooling coil. If the moisture vapor has free passage through the soil and floor to the coils, it is highly probable that the formation of ice lenses and consequent floor heaving would be eliminated.

STOPPAGE OF FLOOR HEAVING

Floor heaving can quite often be stopped but the heaved floor will not, as a rule, reverse itself in any reasonable length of time. The best solution to floor heaving is to prevent it from starting. This can usually be accomplished by the introduction of a heat source at some point below the floor surface. The heat source can be almost any type of heat of a relatively low order of temperature. Sometimes, pipe coils are placed below the level of the floor when the room is constructed. Oil or other non-freezing liquid is pumped through these coils during room operation to carry heat to the sub-soil to keep freezing at a relatively shallow depth and thus prevent the formation of ice lenses of any consequence. A good source for this type of heating is the discharge gas from the refrigeration compressors. The discharge gas is routed through a heat exchanger before entering the condenser and the heat necessary for the floor is extracted and transferred to the solution being circulated beneath the freezer floor. Electric heaters are also satisfactory and are relatively easy to apply to an existing floor without major damage to the floor. Actual depth to place the heaters is subject to some conjecture. Heaters placed at a depth of 2 or 3 ft will certainly prevent icing but also increase the refrigeration load since a great deal of the heat liberated by the heaters will end as additional load in the refrigerated room. Experience indicates that a somewhat greater depth will give satisfactory results with far less passage of heat to the freezer room. Electric heaters of the slug-type have been successfully used for this purpose. These heaters have been placed at a depth of about 10 ft and on 10 ft centers in staggered rows. A heater rated at 400 to 500 watts is usually satisfactory when used at an under-voltage condition both to reduce surface temperature of the slug and to prolong its life. Three 115 volt heaters in series on 230 volt service will normally give adequate performance and long life. On higher voltage systems with 277 volt circuits, four 115 volt heaters in series may be used. An average loading of from 2 to 3 watts per sq ft of floor area should be adequate. The small heater slugs can be obtained with long electrical leads suitable for direct burial. Holes can be drilled to the proper depth for the heater slugs which are dropped in and the interconnections made with airport type cable in slots sawed in the floor. Thermocouples placed at various depths and in several locations under the floor are desirable to determine under floor temperatures and can effect power savings by allowing the heaters to be cut off when not needed. Thermocouples should be placed in 2 or 3 ft (.6 to .9 m) intervals to the depth of the heaters plus 4 or 5 ft (1.2 to 1.5 m) to obtain an overall picture of conditions. Programs can be set up to utilize electric heaters during off peak electrical periods. Temperatures of about 36 F. (2 C) at a 10 ft depth in well drained areas seem to eliminate any serious threats to floor heaving. With pipe coils and a pumped heater fluid, a solution temperature as low as 40° F (4° C) can probably be used although slightly higher temperatures would probably be desirable.

Numerous observations taken over a period of years indicate that there is no certain way to determine whether freezer floors will heave or at what period of time they are likely to heave. If floors are to be used for freezers without commercial insulation, then some type of heater should be installed for use if necessary and are certainly a wise investment as a hedge against future problems. Even the placement of heaters resolves itself into a matter of judgment with some luck and will probably remain so until more exact methods of predicting the soil conditions under freezers shall be found. The heater grid described above was found to be successful in a particular instance but this same installation could prove wrong under a different set of conditions.

Large Freezer Floors

A noninsulated floor in large cold storage rooms represents a considerable savings in first cost. It is, however, a calculated risk since there are certain inherent hazards in this type of construction. Almost every floor location represents some variations in soil characteristics, water tables and other floor details. All of the conditions that can be studied should be weighed in the decision of whether commercial insulation is to be used or not. Obviously such a floor should not be used in coastal areas, or in any area, where free water may be found at shallow depths. This can only lead to ice and heaving problems. In a relatively dry area, however, with porous soil and with no underground free water at shallow depths, a noninsulated floor may work out very well. Heat losses are not excessive and will cause no particular strain on the refrigeration machinery. There is a possibility that any noninsulated floor below the freezing temperature will some day heave, maybe only slightly and maybe a lot. It would seem only good insurance, therefore, to make some provision for underfloor heaters during construction when installation costs are the least, rather than at a later date when they might be required and at a much greater cost. It is very difficult to drill into frozen earth to the depths required for heaters. Also, if heaters are installed after prolonged room use, difficulty will be encountered in loss of space in the room while heaters are being installed.

Floor Heaving Control

The ideal floor surface where no commercial floor insulation is used would be the soil itself. As this is not practical, a concrete floor is usually poured on the ground as a wearing surface. Care should be exercised that no hardeners or other additives are used in this concrete slab that would tend to impede the flow of vapor from under the floor through the concrete to the coils. If water vapor can flow freely from the soil through the floor to the coils, it will be found that the earth immediately below the floor will contain almost zero moisture with the moisture content increasing slowly as the depth increases. If a balance can be reached where vapor can be drawn to the room coils as fast as it enters the soil structure below the floor and there are no vapor barriers in the soil structure, it is possible that heavage will not occur. Unfortunately, conditions can change over a period of time and for this reason heaters are believed advisable.

EARTH FLYWHEEL EFFECT

It is obvious that it will take a much longer period of time to reduce the temperature in a freezer room with noninsulated floor than a freezer room with heavy commercial insulation in the floor. As the room temperature reduces in a noninsulated floor, a considerable tonnage of earth under the floor must be temperature reduced and eventually frozen. Also moisture in the earth will begin to migrate to the cold coil surface and be frozen into ice. Defrosting must be done at shortened intervals until the moisture pull is lessened as freezing of the floor progresses. A room being pulled down with a noninsulated floor will gain temperature very rapidly if the refrigeration is shut off before temperatures are stabilized in the room. A large room may take 90 days or more to stabilize to be a good working room. Loading a room with merchandise before stabilization can only be done with considerable risk of warm up if refrigeration fails during the stabilization period. The opposite side of the coin is, of course, that after a room has been pulled down and the floor stabilized as to temperature, it is difficult to alter the temperature in a short span of time. The frozen earth mass beneath the freezer room exerts a tremendous flywheel effect on the room so that a loss of refrigeration will have very little effect on the room temperature after an initial bounce of a degree or two. Even in a period as long as 48 hours without refrigeration, temperatures will not usually rise more than 5 or 6 degrees F.

In calculating losses from a large freezer room without commercial floor insulation, the calculations will not be different than for a room with commercial floor insulation. The great difference is the pull down period. Extra refrigeration will be required to stabilize the room, it is true, but in the extended pull down period, refrigeration capacity normally figured for working the room is available for the pull down so that normal refrigeration equipment will operate if the room is not worked during stabilization.

Actual observation of a room of some 20,000 sq ft with a noninsulated floor and held at 0°F (−18°C) for several years indicated a very slow warm up after the refrigeration was turned off. After about a 30-day period with no refrigeration on the room, the temperature within the room was still below freezing. Outside temperature averaged about 70°F (21° C). The roof was exposed to the sun and there were cooler rooms at above freezing temperatures on either side.

Floor heaving is an ever present danger in any room held below freezing when the floor is on grade and whether the floor is insulated or not. It may not evidence itself for a long period of time and actually years may pass before heavage will show up. In some instances the floor may never heave but it is an ever present danger. No positive test or method is believed known that can answer the question of heaving before a plant is erected and for this reason, it is a wise precaution to install underfloor heating in all freezers constructed on grade.

FLOORS ABOVE GRADE

Floors above grade with open space below would present no problem from the standpoint of floor heaving, assuming a free air space below the floor. Such floors should be fully insulated with vapor barriers the same as in wall construction. This type of floor is infrequent in the modern one-story cold storage construction but might be found in a low lying area where the building is erected on pilings or piers of one type or another. Special thought should be given to pier construction that direct access by conduction of heat does not take place from ground to the freezer area.

COOLER FLOORS

Uninsulated cooler floors, where temperatures are always above freezing, present no heaving problems. Pull down is still a factor even at cooler temperatures. Excessive moisture conditions beneath the floor can present problems in that excess moisture will be drawn to the coils requiring frequent defrosting and some excess capacity if it continues. Some questions have been raised as to the advisability of switching freezer and cooler rooms every year or two to prevent deep freezing and eliminate the necessity of underfloor heaters. This might be practical except the present day use in most cold storage plants is predominately freezer space and switching could cause considerable operational problems.

INSULATED FREEZER FLOORS

In many instances there is a definite advantage in the use of insulated floors. This is particularly true in low lying areas prone to high water tables or wherever water is close to the surface. Convertible rooms which are changed from freezer to cooler and back at rather frequent intervals will find the flywheel effect of noninsulated floors to be detrimental when warming from a freezer to a cooler. Small rooms also seem to be more adaptable to floor insulation. It should be emphasized that the

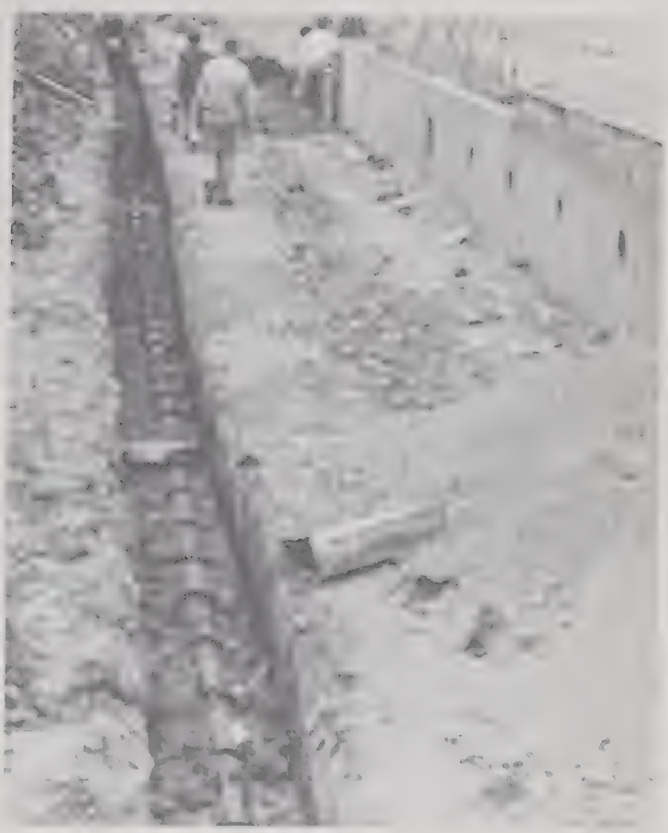


FIG. 9.1. CONSTRUCTION PHASE OF OUTSIDE RETAINING WALL SHOWING OPENINGS FOR VENTILATION TILES. TILES RUN ENTIRE LENGTH OF FREEZERS TO OPPOSITE RETAINING WALL.

Natural circulation through tiles tends to keep fill under insulated floor at above freezing level. Drainage tiles shown in ditch in foreground assure run-off of any surface water.

Courtesy Alford Refrigerated Warehouses

heaving of insulated floors on grade can occur much more rapidly than noninsulated floors unless proper precaustions are taken during construction to prevent heavage. Any insulation on grade, no matter what the thickness, will allow some heat transfer through it. Thus, with the passage of time, an insulated floor on grade can allow the temperature below the floor to drop below the freezing point. This can occur if no means of bringing heat to the subsurface is used. Subsurface moisture can not penetrate through the seal usually used on insulated floors. Thus, if the temperature below the subslab drops below freezing, this moisture will begin to freeze and since it is trapped beneath the floor it will expand and cause floor heavage.

HEATING BENEATH AN INSULATED FLOOR

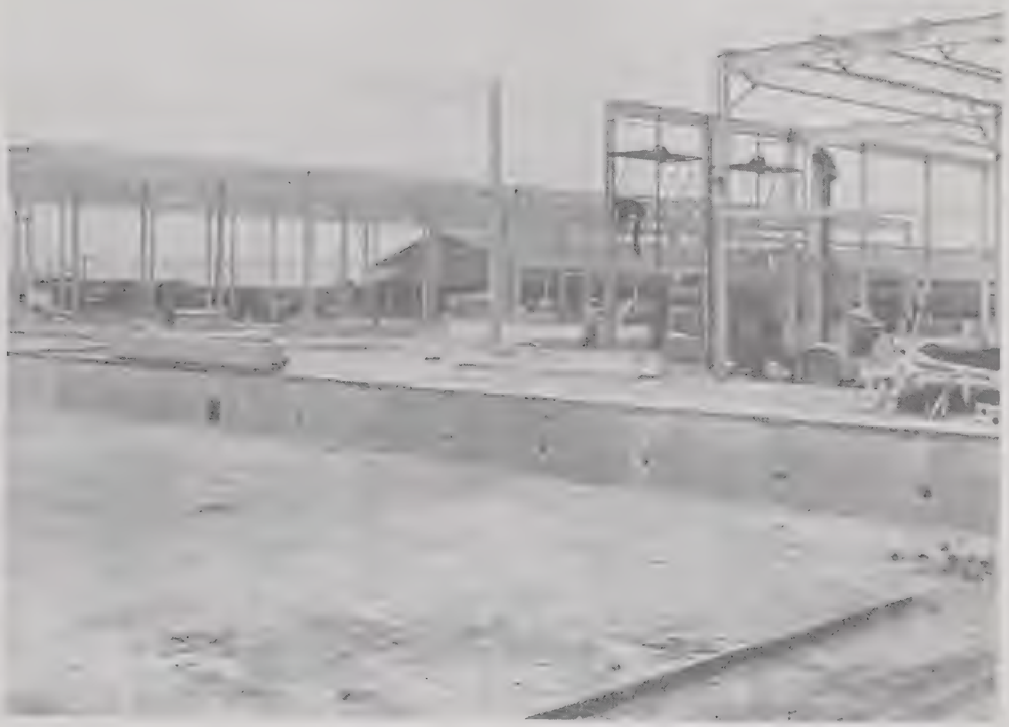
Since in an insulated floor construction, the main barrier to heat transfer is right at the floor level, then heat can be applied closely to the underside of the subslab if desired without affecting the rate of heat transfer through the floor to any appreciable degree. Also, with adequate insulation thickness, the rate of heat transfer is relatively slow and a very low level heat source may be used to prevent freeze up of the subsoil.

Various sources of heat can be utilized beneath an insulated floor such as electric, fluid in pipes or air. Ventilation under the slab is probably the least expensive when it can be used since no energy source is required in temperate climates and only a small amount in colder climates. Satisfactory results have been obtained with ventilation by using 6 inch concrete tile on approximately six foot centers across the freezer room and a foot or so below the subslab at the highest point with tiles pitched for drainage and also as an aid to air circulation. By pitching the tiles away from the prevailing wind the combination of wind pressure plus some cooling of the air will set up a good air circulation through the tiles. The bringing in of the outside air, when it is above freezing, will normally supply enough heat to prevent any icing below the slab. A freezer room constructed on fill at dock height is an ideal application for ventilation since the tiles can be placed in the fill above grade so that both ends are open for easy air passage without mechanical help. Tile need not be sealed at joints and can be loosely laid with only tar paper on other substance at the joints to prevent blockage. Great care should be taken to insure that the passage through the tiles is open before the floor is poured and also after the room is finished since a blocked tile run could allow a spot freezing under the floor with consequent heaving at that location. With good insulation in the floor, temperatures of about 40° F (4° C) can usually be maintained by natural air currents through the vent tiles and where air temperatures are above the 40° F temperature most of the time.

It is still possible to use tile even when freezer floors are not at dock height but on grade, by using mechanically driven fans to drive air through the tiles. Heating the air is not usually necessary except possibly in climates where there are prolonged periods of sub freezing temperature. Even then, if the vents are closed during the cold spells, the heat sink effect of the subsoil will sometimes have enough flywheel effect to prevent the subsoil from freezing. Even if the temperature of the subsoil is below freezing for a short period of time, it is not, as a rule, harmful if circulation is resumed when the outside air temperature is above freezing. Care should always be taken to run ventilating tiles so that any free water that might accumulate will be drained out from under the floor.

Heater electrical tapes can also be used, usually run in conduit either below or in the subslab. When resistance heating is used, it is important to constantly monitor the subsoil temperature so that the heaters are only used as necessary and current is not wasted.

Pipe coils run near the subslab can also be used and an anti-freeze solution such as light oil or inhibited glycol circulated through the coils. A



Courtesy of Alford Refrigerated Warehouses, Corpus Christi

FIG. 9.2. CONSTRUCTION VIEW SHOWING VENTILATION OPENINGS IN DOCK WALL FOR UNDERFLOOR VENTILATION OF INSULATED FREEZER FLOOR.

heat exchanger to heat the solution with discharge gas from the compressors is a satisfactory way to heat without wasting energy.

THERMOCOUPLES IN FREEZER FLOORS

Any floors, insulated or noninsulated, should have some means of monitoring the subsoil temperature. In insulated floors, the temperature sensors should be placed near the subslab to monitor this temperature. Temperatures should be monitored at first at fairly short intervals which can be gradually lengthened as the pattern of the floor temperature begins to stabilize. Do not neglect to take temperatures regularly however, so that potential problems can be corrected before causing damage. Sensors should be placed at varying depths for noninsulated floors.

FLOOR DESIGN STUDY

No hard and fast rules can be made as to when it is economically feasible to use a noninsulated floor or an insulated floor. With constantly rising costs, insulation becomes more expensive. However, the cost of current that must sometimes be used for heaters or other energy cost must also be weighed against the first cost. Length of service desired from a plant is also a consideration.

Probably rooms of less than 5000 sq ft (465^{m^2}) area may be better with insulated floors regardless of soil conditions. Savings in first cost are not too great and in smaller areas the edge losses of refrigeration are of some magnitude since they are a greater proportion of loss in rooms of smaller area. This can require a considerable amount of extra refrigeration. With insulation either in a band around the perimeter or in a trench under the walls, edge losses are reduced but the initial cost begins to approach the cost of full floor insulation.

In larger rooms, considerable study should be given to the use of insulated or noninsulated floors. Dryness of the area both at the present time and historically, as well as the structure of the soil are important points to take into consideration. In dry, high locations, the larger the room, probably the more favorable is the use of a noninsulated floor. Regardless of any soil tests and speculation, it is believed advisable to use a heat source of some type beneath the floor. This is not too expensive when done during building construction and is certainly good insurance against future troubles. Insulated floors, of necessity, must have a means of heating the subslab when they are installed on fill or on grade.

There is really no easy answer to the floor problem for freezers. There are pitfalls and problems regardless of the path chosen. Each room can, and usually does, present a separate problem and needs to be studied at some length before a decision is made as to the best method of proceeding.

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10

Machine and System Selection for Small and Intermediate Storages

Refrigeration for the small and intermediate sized cold storage room is comparatively recent and started from very meager beginnings. In the early part of the twentieth century, ice plants were becoming abundant and manufactured ice was the principal source of cold for the smaller cold storage enclosures. These included grocery boxes, meat market coolers and a few other applications. Ice cream, usually in three flavors only, was sold from retail cabinets that were kept cold by a mixture of salt and ice. Refrigerated enclosures were somewhat primitive in design. Universal refrigeration as we know it now, was unknown. Residential boxes were cooled by ice and the ice replenished as it melted by delivery routes from the local ice plant. The ice manufacturing plants came in for a great expansion during this period.

Ice plants required ammonia compressors and equipment and more and more equipment was manufactured to satisfy the demands for new plants. A considerable number of cooler storages were constructed during this period for the storage of eggs, butter and a few other commodities. Freezer storage was not in much demand and very little development had been done except a limited amount on freezing meats. Ice machine manufacturers started to produce smaller machines for use in the retail meat market, grocery store and kindred uses. The early small ammonia system normally consisted of a small ammonia compressor, belt driven by an electric motor, a water cooled condenser and some controls all mounted on a steel skid. Water for the condenser was supplied from the city main or from a cooling tower. Early cooling towers were of the atmospheric type, often manufactured from woods obtainable locally and constructed by the local lumber yard or cabinet shop. Cooling in the storage area was obtained by expanding the liquid ammonia into steel pipe coils mounted in the ceiling or walls of the box. A second system was also popular in which the ammonia coils were submerged in a brine storage tank to cool a salt brine which was then circulated to other coils in the cold box. This gave a little reserve and sometimes permitted somewhat smaller equipment operating almost continuously and storing excess cooling in the brine, which acted as a flywheel during periods of peak load. Controls were somewhat rudimentary and cumbersome and not particularly reliable so that refrigeration at this stage of the art was somewhat of an enigma, being necessary to meet a dawning demand and, at the same time, being an aggravation.

The development of the small methyl chloride and sulfur dioxide refrigeration systems in the 1920's opened the door to a new era in refrigeration. Ammonia for the small refrigeration load pretty well faded out of the picture as the smaller, lighter weight "low pressure" machines took over the market cooler, small storage, restaurant cooler and other applications. First installations were usually water cooled. However, since the refrigerants did not possess high discharge temperature characteristics, less water was used per ton through a wider temperature range than with ammonia. This resulted in somewhat higher power usage per unit of refrigeration but, at that time, power saving was not a major consideration. It did not take long for the small air cooled condenser to evolve and become popular for the condensing units since it eliminated the fuss and bother and maintenance of water cooled condensing units. The advent of the small air cooled condensing unit and refrigeration system triggered a tremendous surge in the production and use of the small and intermediate sized storage rooms and was to cause a tremendous growth in the cooler and freezer industry within a few short years and also to make possible a great expansion in the use of cooler and freezer products.

Both methyl chloride and sulfur dioxide performed very well as refrigerants but presented certain hazards to both safety and health. The introduction of the halocarbon refrigerants, which were specifically designed chemical compounds for refrigeration to give safety to the use of refrigeration, gave further impetus to the growth of the industry. One of the first halocarbons to come into general use was refrigerant-12. Other refrigerants followed, each designed to some specific parameter, and the use of the halocarbons became almost universal in the refrigeration field for the small and intermediate sizes of commercial refrigeration and all sizes of air conditioning units. Ammonia has gradually been replaced by the halocarbons in this area and it is rare to find an ammonia installation much under 100 tons or so in the refrigeration field. Ammonia has remained popular and is efficient in the larger installations such as meat packers, large cold storages and other process industrial refrigeration.

The dependability and function of controls also improved as more and more units were built so that today, an automated plant, large or small, can be installed and operate reliably by means of the control system designed for it.

The foregoing historical data is a very brief thumbnail sketch of a fascinating period in the growth of a great industry. Many facets have been ignored in the interest of brevity but it is given to illustrate a tremendous growth of an industry that met a need in a very short span of time.

REFRIGERATION FOR SMALL ROOMS

Small refrigerated cold rooms can be found quite frequently in even the largest of cold storage installations. They are quite often used as a lease cooler to some tenant or company or for specialized use. Quite often it is highly expensive or impractical to add such a small unit to a large installation and, because of this an independent system is utilized completely apart from the main plant refrigeration. These small boxes may vary in size from a few square feet floor area up to areas of 2000 sq ft ($185m^2$). It is this size of room that will be considered as the small room. Sizing is entirely arbitrary and for convenience only in separating refrigeration methods.

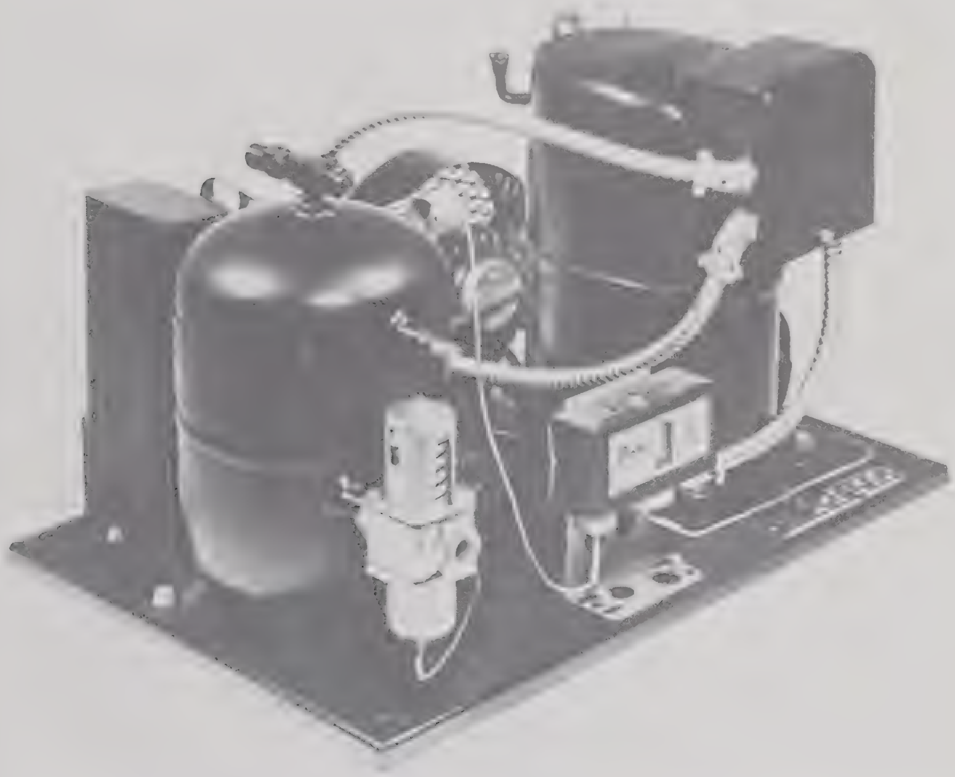
Almost without exception, the small room is refrigerated by means of a halocarbon refrigerant air cooled condensing unit and a single coil inside the cold room. Near the top of this size range, more than one unit with its coil may be used to divide the load and provide insurance against a complete shut down of the plant. The small rooms are usually constructed from prefabricated insulated panels fit together to form a complete room. Floors may or may not be insulated for above freezing temperatures but are usually insulated for freezer applications. With freezer vaults, it is important that attention be paid to bringing heat, in some manner, to the underside of the floor to prevent future heaving. This aspect has been discussed at greater length in Chapter 9.

Refrigerant Compressors for Small Installations

The three types of refrigerant compressors most commonly used for the small refrigeration plant are the full hermetic, semi-hermetic and open type, either belt or direct connected to an electric motor.

The full hermetic motor compressor combines a compressor and electric motor on a common shaft within a steel shell which is welded into a gas tight hermetic enclosure. There is no access to the compressor or motor for repairs except by actually cutting open the enclosure and these units are most often exchanged as a complete unit rather than being repaired.

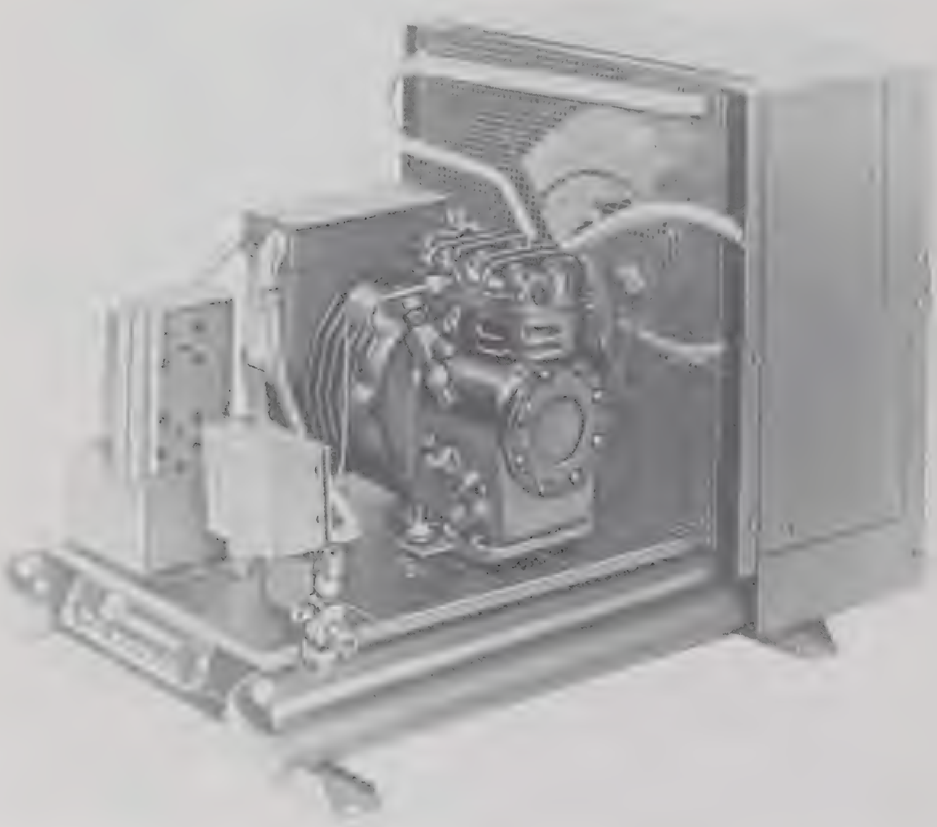
The full hermetic compressor is usually the lowest in first cost. When properly installed, they will do an acceptable refrigeration job although their widest use has been in small unitary air conditioning systems. Speeds vary from 1750 rpm to 3500 rpm. The higher speeds have been used in recent compressor uses since the first cost is less than the slower speed. Overall efficiencies are probably not as high with the higher speed compressors but first cost is considerably lower. This type of compressor is most often used in the small reach-in type cooler or in small walk in boxes where large tonnages are not required.



Courtesy Copeland Corporation

FIG. 10.1. SMALL HALOCARBON REFRIGERANT CONDENSING UNIT UTILIZING FULL HERMETIC TYPE MOTOR COMPRESSOR.

The semi-hermetic compressor is also a direct drive unit with motor and compressor mounted on a common shaft. The motor and compressor are not mounted in a sealed enclosure as in the full hermetic, but usually in a cast body and which is accessible for repairs or replacement of such items as valve plates and other compressor parts. The semi-hermetic is usually somewhat heavier than the full hermetic and is probably more adaptable to cold storage operation in that it can be field repaired in some aspects. Semi-hermetic compressors are made in considerably larger sizes than the full hermetic. Sizes to 40 hp and larger are manufactured in this type of compressor. They are made usually for high temperature, medium temperature and low temperature operation and for a variety of refrigerants. Refrigerant 12, refrigerant 22 and refrigerant 502 are some of the common refrigerants used in cold storage applications. Other refrigerants are also used occasionally for specialized applications. In intermediate sized storage rooms, several compressors may be used with each compressor forming a separate system in the overall refrigeration system so that if one compressor has problems, the other can usually carry the load and keep temperatures from going dangerously high while repairs are being made. Both the hermetic and semi-hermetic compressors present the possibility of system contamination in the case of a



Courtesy Copeland Corporation

FIG. 10.2. CONDENSING UNIT OF THE INTERMEDIATE CLASS USING A SEMI-HERMETIC TYPE MOTOR COMPRESSOR.

burnout in which case the system must be thoroughly cleaned before resuming operation.

In medium and larger sized plants the open type compressor will quite often be found, either belt driven or direct connected to an external electric motor. The compressor is driven by its crankshaft which extends through the compressor body. Refrigerant leaks are prevented around the shaft by the use of a seal. The electrical parts of the system are entirely isolated from the refrigeration circuit thus preventing any contamination if a motor burnout or other electrical failure occurs. With belt drive, the speed of the compressor can be adjusted to meet load requirements within the limits of the compressor and motor capacity. These compressors will quite often operate at relatively low speeds and this tends to increase efficiency and also reduce maintenance costs. Larger compressor units seldom operate at speeds in excess of 1200 rpm for either ammonia of halocarbon refrigerants.

There have also been numerous installations of relatively small size employing the open type compressor. These have apparently been called for in critical areas of temperature or where trouble has been experienced in electrical components in the hermetic or semi-hermetic application. Speed flexibility with belt drives is also an asset on critical loads. The small open type compressor with belt drive presents a relatively high first cost but can be justified by increased efficiency, lowered operating costs and less required maintenance.

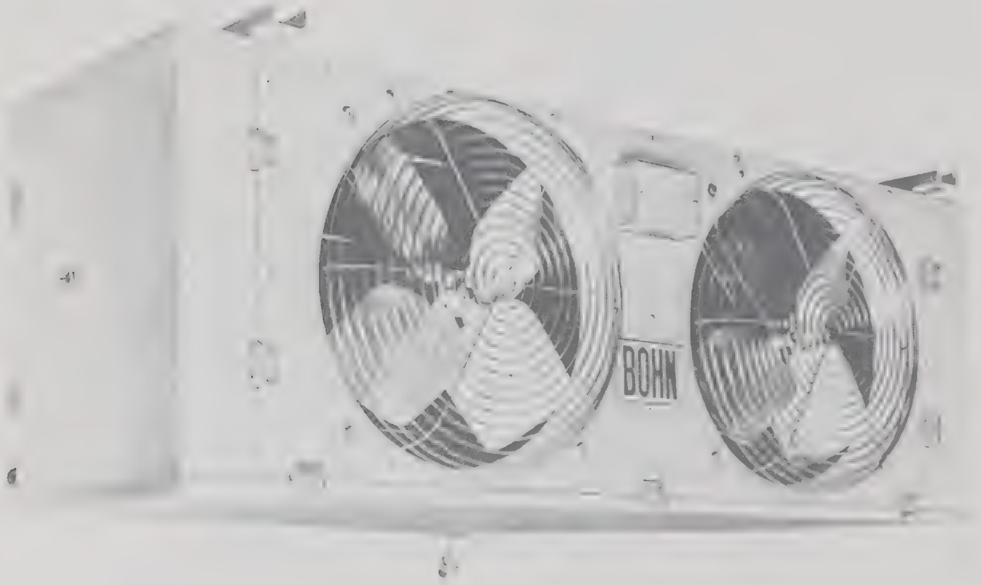
Air Cooled Condensers

Air cooled condensers are used almost without exception for condensing units in the range of the small cooler up to 10 or 15 hp. Smaller units usually are factory fabricated and contain the compressor unit, air cooled condenser and condenser fans, refrigerant receiver, and controls all mounted on a common base. The smaller units are usually standard stock units. Larger units are sometimes custom fabricated and contain somewhat more sophisticated controls and usually can be purchased for outside use on the ground or on the roof and contain adequate covers for weather protection. Some units may also be used with a remote condenser where the unit compressor is at floor level with the condenser remotely mounted.

Air cooled condensers used on stock condensing units are normally adequate to condense the liquid refrigerant at the conditions required to make the manufacturers ratings of the condensing unit. This does not necessarily mean that the condenser is large enough for the best economy in the light of energy shortages and high costs. Manufacturers are beginning to offer more efficient units with larger condensers for more efficient use of power and it is well to check ratings and condensing temperatures before purchasing a condensing unit. Custom fabricated condensing units will usually install whatever size condenser the customer desires. A good rule to follow in air cooled condenser selection is that the condensing temperature of the refrigerant be not more than 15°F (8.3°C) higher than the ambient air over the condenser. This will give relatively efficient service at an affordable cost.

Evaporators

Evaporators are the cooling coils that are placed inside the cold room. They are normally constructed with a finned coil inside of a housing and with propeller fans to circulate room air over the coil and around the cold room. The refrigerant is metered to the coil by means of an expansion valve where it boils (evaporates) to remove the heat from the circulated air. Figure 10.3 illustrates such a coil. Coils are made where the air is blown through the coil by the fan and also where the fan pulls the air



Courtesy Bohn Heat Transfer Division

FIG. 10.3. COLD ROOM COOLING COIL WITH FANS PULLING AIR OVER THE REFRIGERATED COILS.

through the coil. In coolers and freezers, for standard usage, a temperature difference of 10°F(5.5°C) between the refrigerant boiling temperature and the room air is a good basis for selection. Originally temperature differences of 15°F (8.3°C) and higher were used in coil selection. This caused unusually high drying rates for products in storage since the colder refrigerant temperatures tended to remove too much moisture from the air. This has been amended in recent years, so that most coils are now rated at 10° F (5.5° C) by the manufacturers.

In cooler installations, defrost is usually by room air. The refrigeration is shut off and the coil fan kept operating. The room air, being above freezing, will melt the ice off the coil. Time for defrost is usually controlled by a time clock mounted in the control system of the unit which will shut off the refrigeration for a set time and repeat as many times in a day as required.

Freezer coil defrost presents a somewhat more difficult problem. Since the room air is below freezing, external heat must be used to melt the accumulated ice and frost. This can be accomplished by electric heaters placed strategically in or around the coil or by means of hot gas from the compressor which is pumped to the coil and melts the ice by heating the inside of the refrigerant tubing. Both methods of defrost are initiated by time clocks. In freezer applications, it is important that some type of fan delay be used when the refrigeration is turned on so that the coil will be refrigerated before air is forced over it. If the coil is warm when air starts to circulate over it, the warm air will warm all of the air in the freezer slightly. Warm air expands and although the warm up may be slight, a small increase in pressure will result. A very modest warm up can cause enough pressure in a tight room to blow open a door or even to crack walls or rupture the vault at a weak point. Relief doors are sometimes used to relieve this pressure when it occurs, but the fan delay is probably the more satisfactory way to accomplish the desired end. Small vaults are normally very air tight when constructed properly and are particularly susceptible to damage from warmed air. Drain lines from coolers and freezers should be trapped outside the cold room to prevent a back flow of warm air into the vault.

UNITIZED SYSTEMS OF OPERATION

Small and intermediate sized plants as well as some extensions of large plants will sometimes employ a unitized system of refrigeration. This type of system is usually factory assembled in a complete package including the compression highside with compressor, condenser, receiver as well as the low side coil with all controls mounted in a single package which is mounted in the wall of the cooler or freezer. The nearest description of this unit is a very large scale type window unit in appearance. Components, of course, are heavier and for refrigeration service. Such units are made up to sizes of 10 hp or so. It is completely assembled at the factory and shipped assembled and installed at its destination and turned on. The only labor required is the cutting and bracing of the opening to receive the unit and the electrical connections to the unit. Application of this type unit is limited to areas where an outside wall may be utilized that has a free flow of air so that hot air is not trapped or recirculated through the unit condenser.

A second type of unitized equipment is one with the high side or condensing unit in one package and the evaporator, or low side equipment in another. This type of equipment required field installation of the refrigerating equipment but has the advantage of allowing the high and low sides of the refrigeration system to be remote from each other. The condensing unit can be mounted at ground level or on the roof as desired and piped to the evaporator, or evaporators, in the cold room. There is, of course, an advantage in keeping the refrigerant lines as short as possible as there is in any refrigeration application. Sizes of the split system normally run considerably larger than for a single unit system. Multiple evaporators may be used if desirable for air distribution in the cold room. The split system is quite often shipped with all components and controls for an installation except piping connections, refrigerant and external wiring.

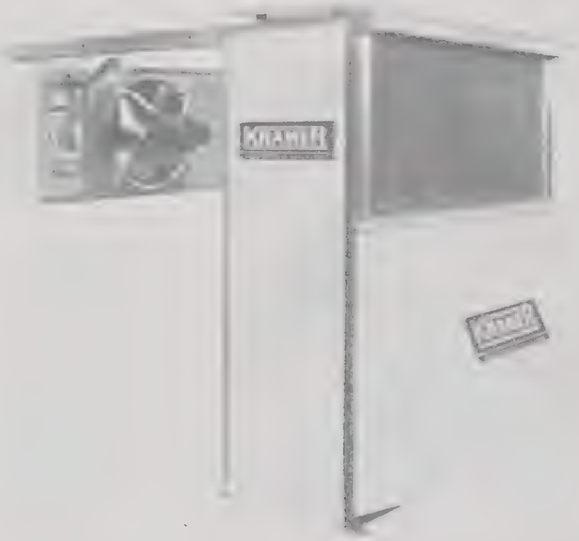


FIG. 10.4. STRADDLE TYPE REFRIGERATION UNIT.

Supports extend through wall of refrigerated room. Condensing unit on outside of insulated wall and cooling unit on inside in refrigerated space. Both units suspended from same supports.

Courtesy Kramer Trenton Company

INTERMEDIATE COLD STORAGE SYSTEMS

Introduction

The size of an intermediate storage system may be considered from as small as 3000 to 4000 sq ft (278 to 372m^2) to as large as 40,000 sq ft (3720m^2). This is purely an arbitrary classification and is used as a break point for the various types of systems discussed in this volume.

At the low end of the intermediate size range, the unitized or simple built up system, entirely automatic in operation would be most often used. This system would, in all probability use air cooled condensers with one of the halocarbons such as R-12, R-22, or R-502 depending upon the temperature range. In cooler rooms above 35°F, an air defrost would most probably be used while at below freezing temperatures, hot gas or electric defrosting would be employed.

Considerably more latitude may be expected in the choice of system as plants increase in size. The unitized system employing a number of split systems will quite often be found in this type of storage. By installing one or more units than required for minimal operation, considerable safety and integrity of temperature may be maintained even with a unit or two shut down for service or maintenance. Automatic control including defrost control is usually standard with this type of unit. While this installation may not be as efficient as some other possible systems, it has the advantage of a low first cost and replacement components are usually available on short notice in case of part failures. Care needs to be exercised that a good routine maintenance schedule is set up since there is a tendency to forget a unit when it is out of sight until complete failure shuts it down. This can become expensive and should be guarded against by routine inspection and check.

The larger intermediate plant is also quite often refrigerated by means of a central engine room. Since a plant of this size is normally rather compact in size, it can be served by either an ammonia or halocarbon refrigeration system with direct expansion evaporators located in the various rooms. Complete automation can be achieved in this system as well as the unitized systems. Under 100 tons refrigeration load, the halocarbon refrigerants would probably be used. Over this figure, an ammonia plant could be used to good advantage.

Compressors

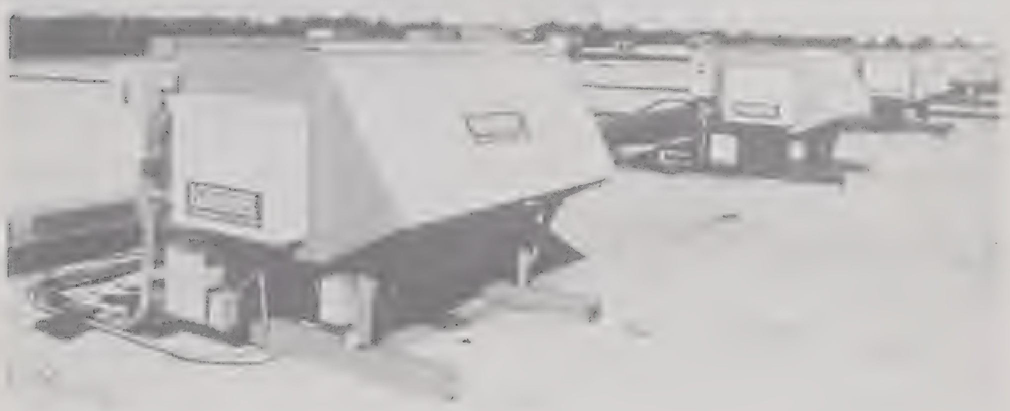
Compressors used for refrigeration will range from a medium sized semi-hermetic type to larger belt and direct driven compressors and can be either halocarbon refrigerant or ammonia. Up to about one hundred tons refrigeration, the most widely used type of refrigeration will probably be one of the halocarbon refrigerants. Above this figure, there is a grey area in which either ammonia or halocarbon refrigerants may be used depending on the type of system to be installed and personal preference. In recent years, a considerable number of systems in the intermediate range have been constructed using a unitized system of refrigeration. There are pitfalls to this type of construction, but with careful engineering and attention to the requirements of the installation, quite satisfactory results can be obtained. This type of unit has proven reliable when properly installed and engineered. It operates automatically without attention as far as the temperature maintenance is concerned. Like all machines and mechanical equipment, however, it should have regular inspection and maintenance. One of the minuses of this type of equipment is to let it operate without attention and inspection until something fails or happens to shut it down. While this is not a design fault, it is often the policy of the owner to forget about it until it may have developed serious problems that can be costly and time consuming.

In the larger intermediate sized plants, a central machine room may be used, particularly for ammonia plants. The compressor will usually be of the direct or belt driven open type mounted on suitable bases for their service. When evaporative condensers are used, the discharge is usually piped to the evaporative condenser mounted above the machine room or alongside of it. A common refrigerant discharge line will be used for the ammonia systems and some halocarbon systems while some other halocarbon systems will utilize split circuits in the condenser with a separate discharge line for each compressor.

Air Cooled Condensers

Most of the smaller halocarbon systems, as well as the unitized systems, and some intermediate sizes may employ air cooled condensers. Small systems are probably best served by an air cooled condenser if the condenser is generously sized to produce efficient operation. This may mean a deviation from a standard unit to obtain better condensing pressure but, in the interest of energy conservation and operating cost, can quite often be justified. Air cooled condensing units are sometimes placed at ground level and when so placed should be located to receive an adequate supply of air and also in a position so that warm air off the condenser will not be recirculated back through the condenser.

If condensing units are roof mounted, attention should be given to their location to prevent air heated by roof radiation from entering the condenser at higher than ambient temperature conditions. Placement of units and insistence of adequate condenser surface are items that now need emphasis. Formerly, with cheap power costs and unawareness of any energy shortages, these items were not of prime importance, but in the light of present day shortages and for the sake of better jobs, they are now assuming, or should assume, prime importance. Another plus in the use of adequate condenser surface is better operation of the whole system and probably much less maintenance cost and fewer break downs.



Courtesy Kramer Trenton Company

FIG. 10.5. AIR COOLED CONDENSING UNITS MOUNTED ON ROOF OF STORAGE ROOM.

Cooling units are hung in cold rooms below. Units can be designed for cooler or freezer service depending on requirements.

During cold weather operation of condensing units with air cooled condensers, the ambient temperature may become so low that insufficient pressure is available to properly feed expansion valves. In systems using thermal expansion valves to feed refrigerant to the cooling coils, which system is used on almost all small and intermediate systems, a relatively constant pressure without too much variation is desirable for the condensing pressure and hence the pressure of the liquid refrigerant to the thermal valves. This is true because of the design of the standard thermal expansion valve which is normally stable over a relatively small range of pressures. If the wide open characteristics of the valve will feed enough refrigerant at lowered pressures, when the ambient temperature rises with consequent pressure rise, the valve may not be able to give stable throttling of the liquid. Because of this an artifically induced head pressure must be maintained by one means or another to assure good operation of the thermal expansion valve. In milder climates where multiple fans are used on the condenser, the cycling of fans on and off controlled by the head pressure may be effective and is probably the simplest method of control. Where ambient temperatures are low, it may be necessary to flood part of the condenser with refrigerant, thus reducing the effective condensing surface so that higher temperature differences will exist thus holding the head pressure at an acceptable level.

It is regrettable that artificial means must be employed to hold head pressure to a higher than possible level in order to maintain a proper liquid flow to expansion valve. This practice consumes more power than should be required and is wasteful in this respect. Some units have been developed in recent years that will allow constant feeding of the refrigerant over a wide range of pressures and thus take advantage of low head pressures with consequent power savings in compressor operation during periods of low ambient pressure. Satisfactory results can also be obtained by alternate use of more than one expansion valve so that a large valve is used for low ambient and a smaller one as pressures rise. Any system that will reduce power costs by allowing condensing pressure to stay low should be given consideration. First cost will be higher and may be prohibitive, at the present time, for very small systems. However, as power costs rise, an increasing amount may be spent to save on power consumption.

Water Cooled Condensers

Water cooled condensers are a second method of condensing and are now rarely used on the small installation but can be used on intermediate sized installations, above 10 hp. The water cooled condenser offers lowered head pressure, particularly during peak weather conditions. Higher maintenance costs may be encountered in the use of water cooled equipment. Water cooled systems formerly, in smaller sizes, operated on city water which was wasted to the sewer. Unfortunately, water systems of cities are now pretty well taxed for capacity and so wasting of water through a condenser is usually prohibited. The alternate to wasting water is the use of a cooling tower which allows recirculation of water and cooling the water by the ambient air. Temperature of the water out of the cooling tower is then governed by the wet bulb temperature of the ambient cooling air through the cooling tower. Cooling towers give good results when adequately sized to the load imposed on them and when used properly. Since cooling is obtained by evaporation, certain solids are left in the tower which can cause dangerous scaling in the condenser unless properly disposed of. These solids can be handled in some locations by a bleed off of water from the condenser allowing fresh water to dilute the solids to a point where they do no harm. In some other areas where water is not good, chemicals may be needed, in addition to bleed off, to operate the water system properly. As stated before, cooling towers are not used on small systems due to first cost and high maintenance expense for the small system. When used in larger systems, the temperature of the water off should be kept as low as possible. This serves a dual purpose, in that the lower water temperature will allow for lowered head pressures and consequent power savings and also the lowered pressures (temperatures) will usually make for less scaling of the condensers. As an example, a good cooling tower where the wet bulb temperature is 78° F (25.5°C) should produce cooled water at not higher than 85° F (29.5°C). With 4 gpm (15 liters/min.) of water per ton refrigeration, a good condenser should then produce refrigeration condensing at not higher than 95° or 96° F (35° to 35.5° C). The above conditions have been used for a long time for ammonia plants but the halocarbon water cooled units are normally designed for somewhat higher conditions. However, with increased power costs, systems with the best possible efficiencies may become not only the most desirable but also the most economical.

Indirect Water Cooled System

An alternate to the water cooled condenser system that has been used with considerable success in systems having multiple condensing units, such as in a large supermarket, is the indirect water cooled system. In this system a closed water loop is maintained through the various condensers of the condensing units. Since this water is in a closed loop, it can be permanently treated so that there is no scale buildup in the small condensers, thus allowing them to operate at peak efficiency at all times. The water circulating through the individual condensers is pumped through a pipe coil located in a cooling tower where the spray water from the cooling tower indirectly cools the water circulating through the coil without any contamination. The usual form of this tower is an evaporative condenser in which the normal refrigerant coil is used to cool the condenser water. With a properly designed system, comparable condensing temperatures can be obtained to those in a standard water cooled system employing a cooling tower and condenser. The advantage is two-fold: no scaling occurs in the individual unit condensers and scaling is also a minimum in the water cooler since the temperature of the water entering the coil of the tower is not as high as discharge temperatures of refrigerant would be in an evaporative condenser installation, thus decreasing scale in the evaporative water cooler. During cold weather, water from the unit condensers can be diverted through a coil in the air conditioning system, thus providing some of the heating needs for the building or market. This system has considerable flexibility and water temperatures are rather easily maintained at any desired level by fan control of the indirect cooler.

Evaporative Condensers

The evaporative condenser is used extensively in larger installations. It combines the functions of a condenser and cooling tower into one unit. It can also be used in multiple installations by dividing the coils into individual circuits so that each condensing unit is served by its own coil. The condenser usually consists of a metal enclosure with a fan blowing air through the enclosure. Inside are pipe coils. For halocarbons, the coils may be made of copper or steel. A sump is provided beneath the coils and water from this sump, or pan, is circulated by pump over the coils, either by a spray bar or other means. The circulating air cools the water which also condenses the refrigerant in the coils over which it flows. The water returns to the sump where it is recirculated. Evaporative condensers are efficient if sized with care and with sufficient capacity to adequately handle the load imposed. Condenser surface is normally a very good investment in any plant and dollars invested will usually return in multiple.

Evaporators

The evaporator or cooling coils placed within the refrigerated enclosure most often consist of a single finned evaporator coil, within which the refrigerant boils, enclosed in a metal housing with a propeller fan, or fans, which either forces air through or pulls air through the coil and circulates it around the cold room. Film spacing on the coil may vary from 3 to 8 fins per inch. At temperatures approaching the freezing point and below, wider fin spacing is desirable to help prevent too rapid frost build up between the fins. At higher temperatures, closer fin spacing may be used. Adequate drain connections must be made from the pan beneath the coil so that the condensate from the coil can be carried outside the room. Drain lines should be trapped when extending outside of the cold room to prevent entrance of warm air into the cold space through this line. Trapping should be done on the warm side so that no freeze up will occur.

DEFROSTING EVAPORATOR COILS

Defrosting of cooler coils where the air temperature is 3 or 4 degrees above freezing is rather easily accomplished by shutting off the refrigeration for a period of time and allowing the room air to melt the accumulated frost off of the coil. This is usually done two or more times a day depending upon the conditions of use and may be accomplished automatically by a time clock.

Where a room is below freezing, defrost must be accomplished by supplying heat in some manner to the coil. This can be done electrically or with hot discharge gas from the compressor or by water. All three systems are in use in some plants. For room temperatures down to 0°F., electric defrost is satisfactory and is quite widely used in small plants since it is easy to automate and simple to install and is relatively trouble free. It is usually necessary to install a larger electrical service than normally required for unit fans to handle the load of the electric defrost. Hot gas defrost will do a rapid job since the heat is placed inside the evaporator tubing and hence no undefrosted sections will be found when the system is operated properly. Hot gas will operate on much colder temperatures normally than electric heat. Water defrost is a simple means of defrosting by flooding the outside of the coil with water and melting away the frost. It is rather difficult to automate properly and is not used as frequently as the other methods.

HUMIDITY CONTROL

In most standard conditions for the small and intermediate cooler, a relatively high humidity is desirable to maintain storage without undue dehydration. Water vapor is removed from the air by lowered temperatures. It is therefore important that the temperature difference between the room air and the refrigerant be kept to a minimum to prevent excessive drying of the air. A temperature difference of not more than 10° F (5.5° C) is desirable in both cooler and freezer installations to prevent excessive dehydration of product. Also at less temperature differences, frost does not build rapidly and defrost is required at less frequent intervals. The higher refrigerant temperatures also make for more efficient operation and less power cost.

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11

Machinery and System Selection—Large Cold Storage

Large cold storage facilities of 40,000 sq ft (3716 m^2) and over will normally require in excess of 100 tons refrigeration regardless of the division between cooler and freezer space. Trends in recent years seem to point to the larger plants since a considerable volume must be handled in public warehousing to be profitable. No hard and fast lines can be drawn as to a minimum size of warehouse that can be profitably operated as an individual enterprise and the rapidly changing economic situations of the past few years make even approximations a risky business. Observation would indicate that warehouses of less than 40,000 sq ft (3716 m^2) refrigerated areas find it difficult to show a profit when operated strictly as a public house for storage by contract or space lease. Smaller houses, of course, are justified when used in connection with, or as a part of, a business requiring refrigerated space for its own products.

REFRIGERANTS FOR LARGE REFRIGERATION PLANTS

Ammonia, as a prime refrigerant, probably remains in a favored position in most of the large cold storage facilities. It is normally used in a central machine room containing multiple compressors and other components of the system and cooling the various cold rooms either directly by the evaporation of the ammonia liquid within the coils in a cold room or by the chilling of brine with ammonia in the machine room and the cold brine being circulated to the various cold rooms for cooling these rooms. There are a number of valid reasons for favoring the use of ammonia as a refrigerant. Refrigeration compressors may be paralled with ease. There are normally no serious oil problems with ammonia systems as oil is not usually returned via the suction line. Since oil returning velocities do not have to be maintained in suction lines, long lines may be designed with very low pressure drops. Low refrigeration cost with excellent operating efficiency and high flexibility all help to make ammonia a desirable refrigerant. Over a span of many years, much data has been collected on ammonia and its operation as a refrigerant. Many engineers and plant designers of cold storage facilities are very familiar with ammonia and ammonia equipment from years of experience and are very confident of a design involving ammonia equipment; hence, many tend to design ammonia plants as a matter of course.

Unfortunately, in the past few years, competent ammonia plant operators have become a rather scarce commodity in many parts of the country. As older operators and chiefs have retired, it has been difficult to find and train new people to take the places of those who have retired. While it is true that the newer fully automated plants do not require as many operators as the older manual operations required; yet the personnel required must be of a topflight capability to keep the plant in peak operating efficiency. A fully automated plant does not mean an unattended plant. In larger plants, maintenance personnel are important and are usually hired on a yearlong basis. This type of personnel is also becoming scarce. In some areas, scarcity of good operating and maintenance personnel, particularly in the ammonia field, is a source of concern to cold storage owners and managers.

The large cold storage plant design can take many roads. Individual preferences, type of storage expected and many other considerations can all have an effect on the design and type of installation desired. The following pages are written to give a description of some of these systems and comments on their performance. As stated before, no one design is completely right for a facility and numerous designs can be considered proper depending on the individual preference of the designer and owner.

In some critical areas, design concepts have swung to the halocarbon refrigerants. First class operating personnel and maintenance mechanics are also scarce in this field but a considerable number of service and construction personnel have some knowledge of halocarbon refrigerants from an air conditioning standpoint and can be trained, over a period of time, to perform reasonably well in the operation of the large refrigeration plant employing halocarbon refrigerants.

The owner or manager of a new cold storage facility is faced with the sometimes difficult choice of finding competent personnel to operate an ammonia plant or in a halocarbon plant or to induce personnel with less than adequate knowledge to seek training to upgrade themselves. Sometimes it is only necessary to find a good chief engineer who will proceed from that point to find and train the necessary operators and maintenance mechanics needed.

Unfortunately for the reputation of the halocarbon refrigerants, the operating criteria used for these plants has historically been less efficient than for ammonia plants with standard ratings of compressors.

A condensing temperature of some 10°F. (5.5° C) higher for the halocarbon refrigerants as opposed to ammonia is normally used and shown in the rating tables by most manufacturers. The operating costs for the halocarbon plant will always show up higher than for ammonia when two standard designs are submitted since the halocarbon standard will, as a rule, be designed for a higher condensing temperature than ammonia. The higher temperature also causes higher discharge gas temperatures from the compressor, increased horsepower, and in water cooled condenser applications earlier formation of scale due to the higher condensing temperature and hotter discharge temperature to the condenser. Limited condenser surface also causes a "snowball" effect of promoting more scale, higher temperature, more scale, etc. All of this causes excessive operating problems and the excessive power cost over ammonia causes a weighted decision in favor of ammonia. The first cost is considerably lower for a halocarbon refrigeration plant, as described above, than with ammonia but when operating and maintenance costs are estimated, the results are hugely in favor of the ammonia plant.

RATING OF REFRIGERANT COMPRESSOR SYSTEMS

Air conditioning installations over the past several years have triggered a tremendous growth in refrigeration equipment for air cooling. Almost without exception, refrigeration equipment for air cooling has been designed for use with one of the halocarbon refrigerants. Extremely keen competition in the air conditioning field has resulted in the selection of equipment usually based on a low first cost rather than efficiency. High operating costs have not been a great factor in the past since power has been inexpensive and first cost has been the primary consideration. Unfortunately, some of this practice spilled over into the industrial refrigeration field, in many instances, by designers who were not fully aware of the requirements of the industrial refrigeration plant. In some cases, manufacturers data which was never intended for use in industrial applications has been used with frequent failures. The shortage of energy and conservation practices now being demanded by both the government and the individual pocketbook may soon bring the standards of refrigerating equipment to a higher level. This is desirable since it has never been good policy to waste energy, even when it was cheap.

APPLES TO APPLES

In comparing various refrigerants for use in warehouse operations, they should be compared on an "apples to apples" basis. The same condensing temperatures, evaporating temperatures and other conditions should be used for all refrigerants. There is no reason to penalize the halocarbon refrigerant system with a condensing temperature higher than necessary for best efficiency. There are some differences between refrigerants in the power required per unit of refrigeration. These are not too great to allow the use of a preferred refrigerant over another one. The greater power difference is in the use of a refrigerant at higher than necessary condensing pressure. Table 11.1 illustrates the percentage differences in power and compressor capacity under varying condensing temperatures. It can clearly be seen that much power can be wasted if condensing temperatures and corresponding pressures are not maintained at the lowest possible level.

TABLE 11.1. COMPARATIVE PERFORMANCE OF COMPRESSORS UNDER VARYING CONDITIONS OF CONDENSING TEMPERATURES (PRESSURES) AND USING 95°F (35°C) AS A NORM - 100%. *

Condensing Temperature		% Horsepower per unit refrig.	% Comp. Capacity available
°F	°C		
85	29.4	87	107
90	32.2	93	104
95	35.0	100	100
100	37.8	108	96
105	40.6	115	93
110	43.3	123	89
115	46.1	130	85
120	48.9	138	82
125	51.7	149	78
130	54.4	157	74
135	57.2	164	71

* Above data is an average of compressor manufacturers data on R-12 and R-22 heavy duty industrial type mult-cylinder compressers and at 25°F (-3.9°C) suction temperature. Almost any heavy duty compressor and refrigerant will follow the above pattern within the range of the refrigerant.

When heavy duty equipment is used and like conditions are compared, the differences in refrigerants used are not too great. These are operating differences and system differences that need to be worked out in the plant design but the end results are not too far apart with proper design and selection for industrial use.

GOOD DESIGN OF REFRIGERANT COMPRESSORS FOR COLD AND FREEZER STORAGE

The good designing engineer, regardless of the refrigerant used, should design on sound engineering principles. The system he recommends should not only perform all the functions desired by the owner but should also perform efficiently and economically and with a minimum of costly maintenance. This type of plant will have a higher price than a plant designed strictly for competetive advantage but it must be remembered that in a cold storage facility, equipment is operated 24 hours a day and 365 days a year and that efficiency is still an item to keep paramount and low operating costs are to be desired and demanded. With ever rising energy costs, it becomes more and more important to achieve highest efficiency for lowest operating cost.

Ammonia equipment, over the years, has been used primarily in the industrial field and has been designed for heavy duty use. The standards set long ago for ammonia compressors and other equipment was predicated on long life and favorable maintenance costs. Also, most ammonia plants are tailor made rather than a packaged standard product and considerable design expertise is usually required for a high efficiency plant. Too often the cost of an ammonia installation with heavy duty equipment has been compared to standard halocarbon package units designed for a low first cost rather than any great efficiency. The comparison is obvious on a first cost basis but not so apparent when operating costs are considered. In any cold storage application, if successful operation is to take place, the refrigeration equipment, be it ammonia or halocarbon, should be heavy duty type built for the service it is intended.

It is very possible and desirable that in the coming years, equipment and refrigerants will come into being that will change the present concepts of refrigeration. Present state of the art however, does not show indication of any radical change. There has been much work done to promote the halocarbon refrigeration systems, particularly in air conditioning, and with a considerable degree of success. In the highly competetive field of air conditioning, the first cost has been a prime factor in selling equipment and because of this, not too much effort has been expanded in the building of more efficient compressors and heavier duty equipment for the industrial field. Some relatively heavy duty halocarbon refrigeration equipment does exist and, in industrial uses such as cold storage, can produce good results.

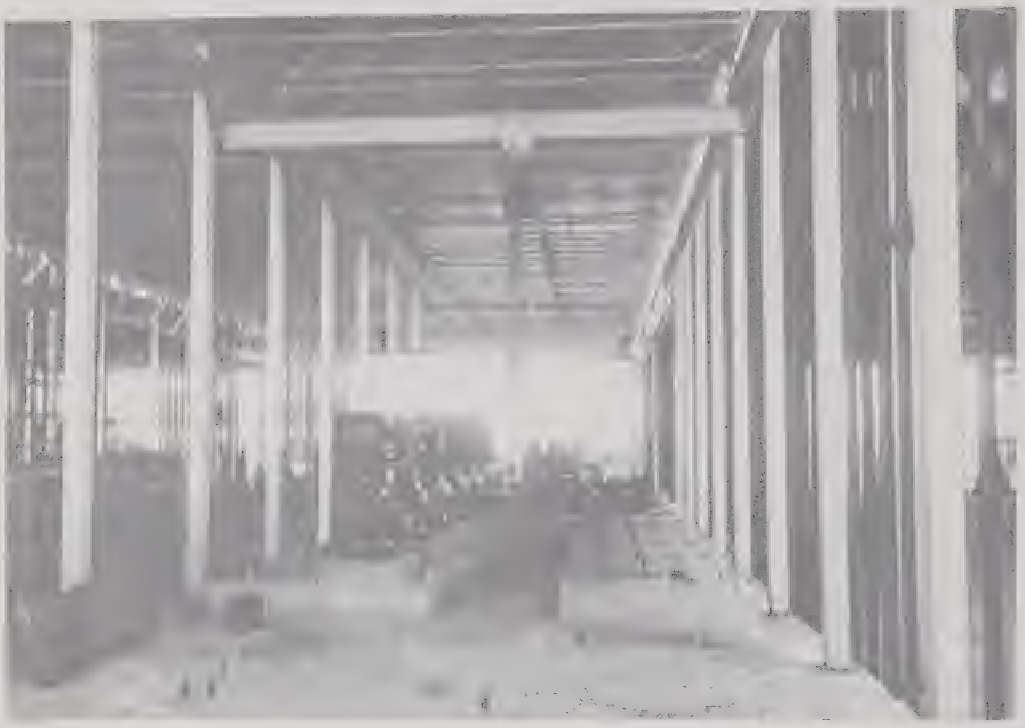
The foregoing is not meant as a criticism of any refrigerant but rather a plea that all factors be studied in designing a cold storage facility and that when a particular refrigerant has been selected, care be exercised to pick the best and most efficient system possible. The greatest use of the halocarbon refrigerants has been in the air conditioning and smaller commercial field and the concentration of product has been in that direction with lighter weight less expensive equipment than used in the heavier industrial field. Conversely, ammonia, because of its peculiar properties and hazards has been best used in the industrial field and hence manufacturers of ammonia equipment have concentrated on heavy duty equipment suited to this field. There are, of course, cross overs from one field to another and there are grey areas in either field. It is expected that greater attempts at more efficient equipment will be forthcoming as power costs become higher and efficiency and low operating costs become more desirable. Efficient equipment does exist in both the ammonia and halocarbon field and should be used in any installation such as a cold storage where equipment must run continuously and reliability is paramount.

DIRECT AND INDIRECT COLD STORAGE REFRIGERATION PLANTS

There are essentially two types of cold storage refrigeration plants. These are the direct and indirect systems. In the direct system, direct expansion coils are used in the cold rooms fed directly from the plant refrigerant with the compressors and high side equipment located in a central engine or machine room. The indirect system also utilizes a central machine room and adds brine chillers to the equipment. Brine is chilled in the machine room in the brine chillers and circulated by pumps through pipe lines to the various cold rooms and through coils in fan coil units located in the room which cool the room air. Not all plants are all one type or the other and both types may be often found in the same plant although one system will usually predominate.

The normal large cold storage facility will utilize at least two and sometimes more refrigerant temperatures. One refrigerant temperature is required for cooler and another lower temperatures for freezer storage. In addition to these two rather basic requirements, a still lower temperature may be required if commercial freezing is being done and also higher than cooler temperatures may be required for some specialized storages. Dry storage space is sometimes cooled to 70 or 80°F (21 or 27°C) during hot weather since this temperature will prolong the storage life of some canned goods and other commodities normally held in dry storage. This requirement is quite often best served by chilled water units in the conditioned space and requires an addition of a water chiller at a relatively high (above freezing) refrigerant temperature.

A central machine room serving a large cold storage may operate with from 2 up to 4 or 5 refrigerant temperatures to serve the various demands for temperature. One of the chief advantages of the central machine room is flexibility, in that multiple machines may be switched to suit various loads and conditions. This is particularly true in an ammonia installation where changing compressors to different conditions does not entail any difficulties. Somewhat more care must be exercised in switching halocarbon refrigerant compressors but spare machines can be valved to perform varying functions. Cross connections are of great advantage in the large machine room for ultimate maintenance of temperature and flexibility of operation.



Courtesy Alford Refrigerated Warehouses

FIG. 11.1. CONSTRUCTION VIEW OF COMPACT WAREHOUSE MACHINE ROOM SHOWING COMPRESSOR FOUNDATIONS WITH SOME COMPRESSORS.

Note overhead crane used during construction and retained for various purposes after plant in operation.

Freezer storage refrigeration is most often handled by booster or 2 stage operation, particularly in ammonia installations. The boosters normally discharge at an intermediate pressure that can be used for the cooler storage refrigerant temperature. The optimum booster compressor discharge may be somewhat at variance from the suction pressure required for the coolers but usually is close enough to a common pressure that the common pressure may be used without losing any great amount of efficiency in the booster operation. Piping is also saved by using the booster discharge and cooler suction at the same pressure. Air conditioning (dry storage) and other specialized temperature ranges may require additional suction pressure headers and machine connections. High stage compressors should be valved and cross connected so that multiple selections can be used and so that compressors can be taken off the line for service without interrupting the operation of the plant appreciably. Variations in the cross connections of compressors will be found in each plant depending upon the refrigerant used, size of compressors and distribution of loads in any particular plant. Regardless of the arrangement of compressors and loads, flexibility and safety in the central machine room plant can be achieved by the proper assortment of compressors and the proper cross connections and valving of the various pressures.

In a typical machine room for a large cold storage facility, it is desirable to operate with high stage compressors in the range of 100 to 200 tons each. There is an advantage in utilizing compressors of equal size or multiples of each other from the standpoint of maintenance parts required. Good practice dictates the installation of a spare machine or two in the large plant; these machines usually cross connected to serve any load where needed. This effectively reduces plant down time of any part of the plant and insures more reliability.

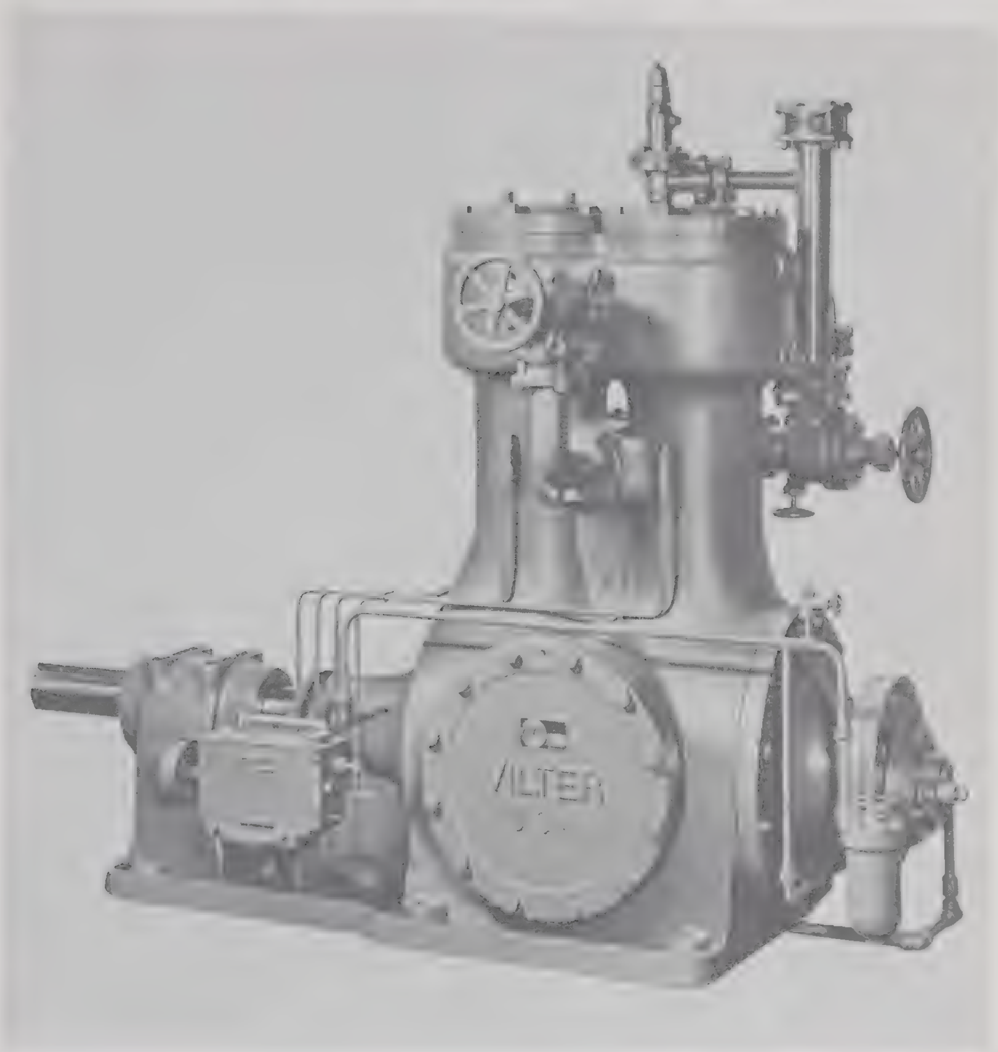
COMPRESSORS, HIGH STAGE

Probably the earliest and certainly the greatest in use in the compression refrigeration system is the reciprocating compressor. Early compressors were usually of a large bore and stroke and were driven by a steam engine at slow speed. A great number of these compressors were horizontal, double acting and many operated at speeds below 100 rpm. Large flywheels were used to assure momentum through the compression stroke. Most of the compressors were driven by connecting rods from a cross-head on the engine through a stuffing box to the ammonia piston. Some vertical compressors were also built along these same lines but with vertical cylinders. These rather massive units, sometimes two stories in height, were used in ice plants and other applications. Very heavy concrete foundations were required for those monsters to prevent them from walking out the door and up the street. Strangely enough, these early compressors were quite efficient and ran for long periods of time without requiring an overhaul. Ammonia was used almost universally as the refrigerant. Some of these old compressors were in service until comparatively recent times.

Following the original compressors of massive size, an interim period existed and various types of compressors and drives were used experimentally and there gradually emerged a smaller compressor. The original compressors required large amounts of floor space for proper installation and the newer models were designed for more compact installation. The horizontal double acting compressor was improved and used with electric motor drive, usually being connected between two cylinders on a common shaft with the rotor of a synchronous motor being used as the flywheel for the compressor.

There eventually emerged the vertical single acting (VSA) compressor with the cylinder combined in one casting with the crankcase and eliminating the stuffing box and crosshead drive by substituting connecting rods from a crankshaft and a seal against gas leakage where the rotating shaft emerged from the crankcase. The total weight of these newer compressors was considerably less than the older massive compressor although still quite heavy by todays standards. The new compressors were made in a wide range of sizes from a bore of 3" (7.6 cm) or so up to about 12" (30.5 cm). The stroke was usually close to the diameter of the piston. Speeds ranged from up to about 400 rpm for the small compressors down to 300 rpm for the larger ones. Most of the VSA compressors consisted of two cylinders with a few being constructed with four. A piston speed of 600 ft per minute was considered maximum. The VSA compressor was used almost exclusively during the 1920's and 1930's with ammonia refrigerants. These machines were efficient in operation and were usually figured with ample condenser surface and other accessories to make a very good and energy efficient job. Heavy foundations were still required for these compressors. Various drives were used including synchronous motor drives with the rotor of the motor acting as a flywheel for the compressor, belt drive and belt and direct connection to internal combustion engines. There are still quite a number of the VSA machines still in operation and still giving good service although the manufacture of these compressors has decreased during the years in favor of smaller more compact compressors which entered the market several years ago. The VSA machine is still a good efficient compressor and will last many years if operated correctly and is given, at least, a minimum of maintenance.

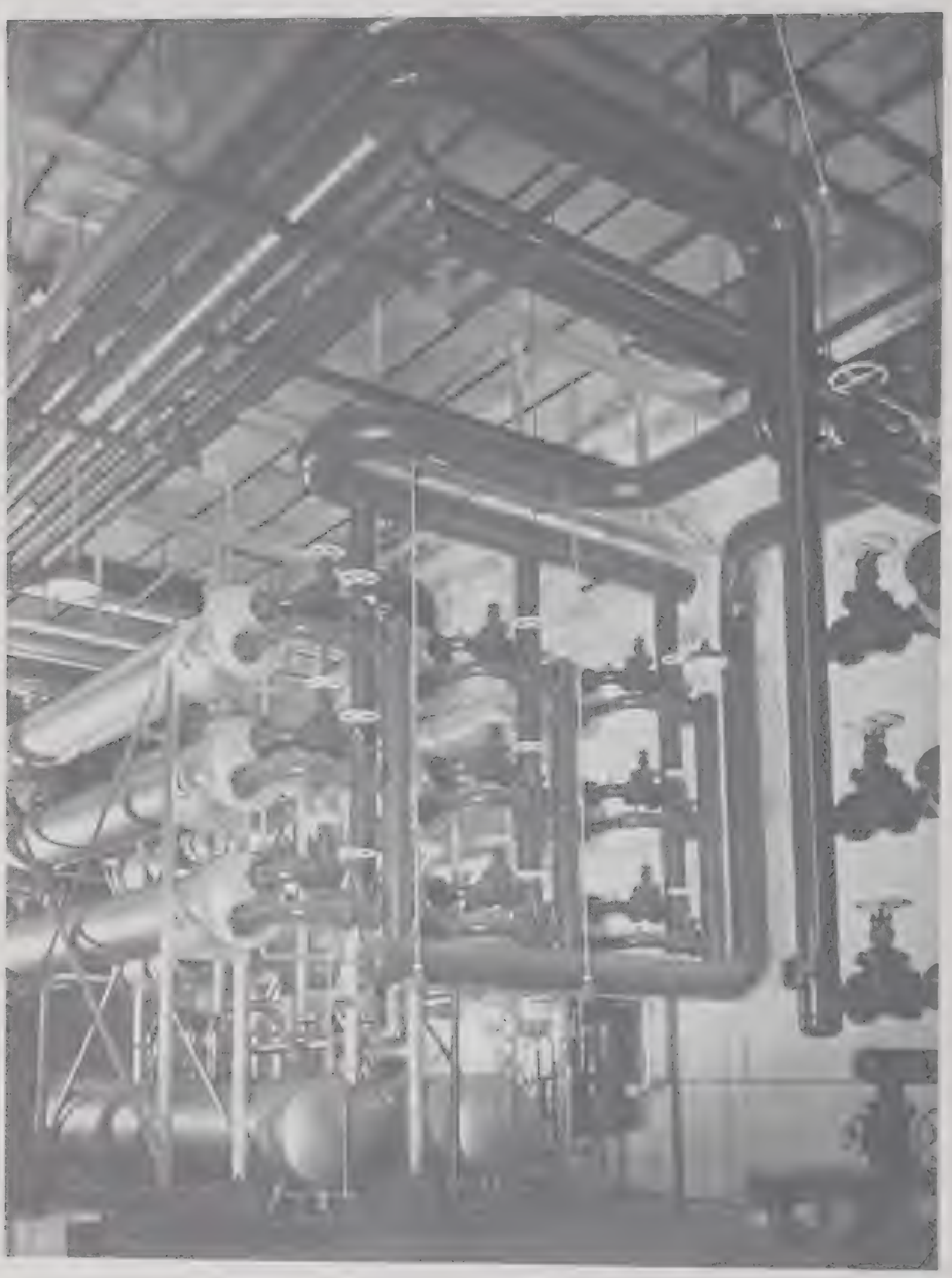
In the ammonia field, the VSA compressor is still much in vogue but has changed to a smaller, more compact compressor with small bore and stroke cylinders in multiple and operating at higher speeds than the older large VSA compressors. The design of the newer compressors reflects the increasing costs of space in a machine room as well as in the cost of machinery and reflects a very good compromise with the older larger VSA compressors. Most of the newer compressors will be of the multicylinder type with cylinder bores in the area of 3 to 6 inches (7.6 to 15.2cm) with a stroke equal to the bore or slightly less. Compressors will be found with from 2 to 16 cylinders and operating at speeds in the range of 1200 rpm to 1750 rpm. These speeds allow for direct connection of the compressors to standard induction motors operating at these speeds. Forced feed oiling is usually standard and capacity control can be obtained by unloading cylinders by means of oil pressure generated by the compressor forced feed oil pump. Much lighter foundations are required for these compressors since they are inherently well balanced. Efficiency of these compressors is good and they may be considered as a heavy duty type. They are manufactured for both ammonia and halocarbon use in the refrigeration field. These compressors, when installed in multiple,



Courtesy Vilter Manufacturing Corporation

FIG. 11.2. TWO CYLINDER VERTICAL SINGLE ACTING COMPRESSOR.

have the advantage of requiring a rather limited stock of parts since a great many of the parts are interchangeable. Cylinders are normally equipped with liners and a complete rebuild of a compressor can be accomplished in relatively short order. These compressors, in a heavy duty type, have become more or less a standard type for use in cold storage plants and other industrial refrigeration applications. The efficiency is good. Life expectancy is long and space requirements are not great. It can be direct connected or belt driven. It can also be used as a high stage compressor or as a booster although the cost is relatively high for booster service which does not normally require as heavy a machine as the high stage application.



Courtesy Alford Refrigerated Warehouses

FIG. 11.3. MULTIPLE SHELL AND TUBE CONDENSER INSTALLATION

Note looped water lines for equal pressure drop through all condensers and refrigerant receivers located beneath condensers.

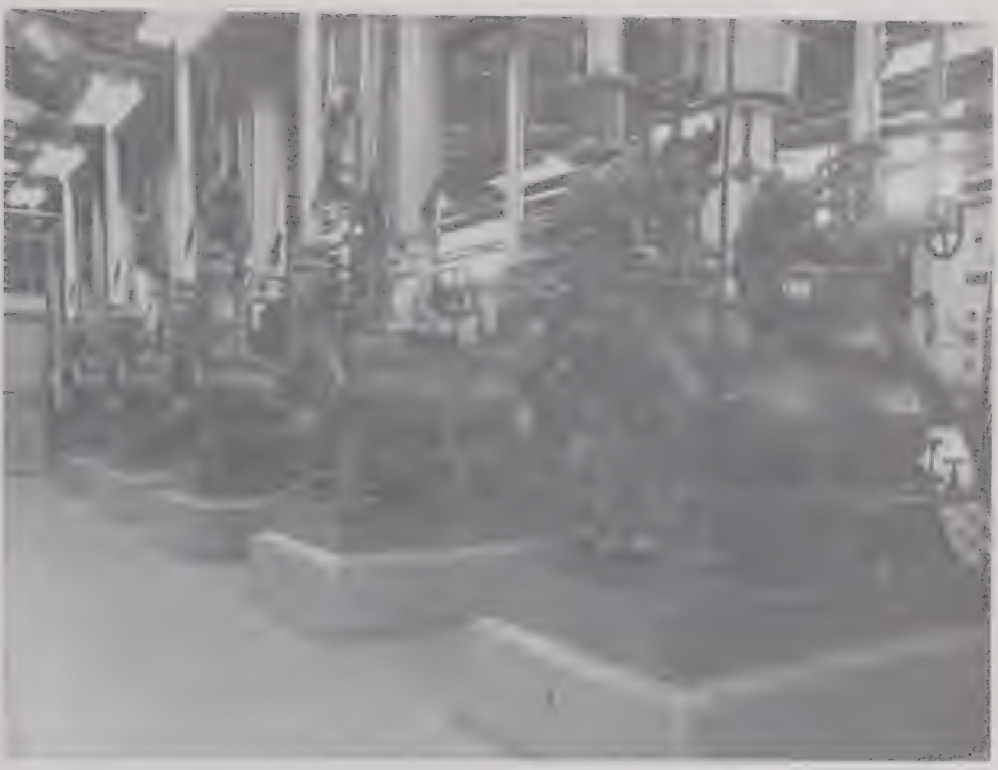


FIG. 11.4. MODERN COLD STORAGE MACHINE ROOM SHOWING HIGH STAGE AMMONIA COMPRESSORS.

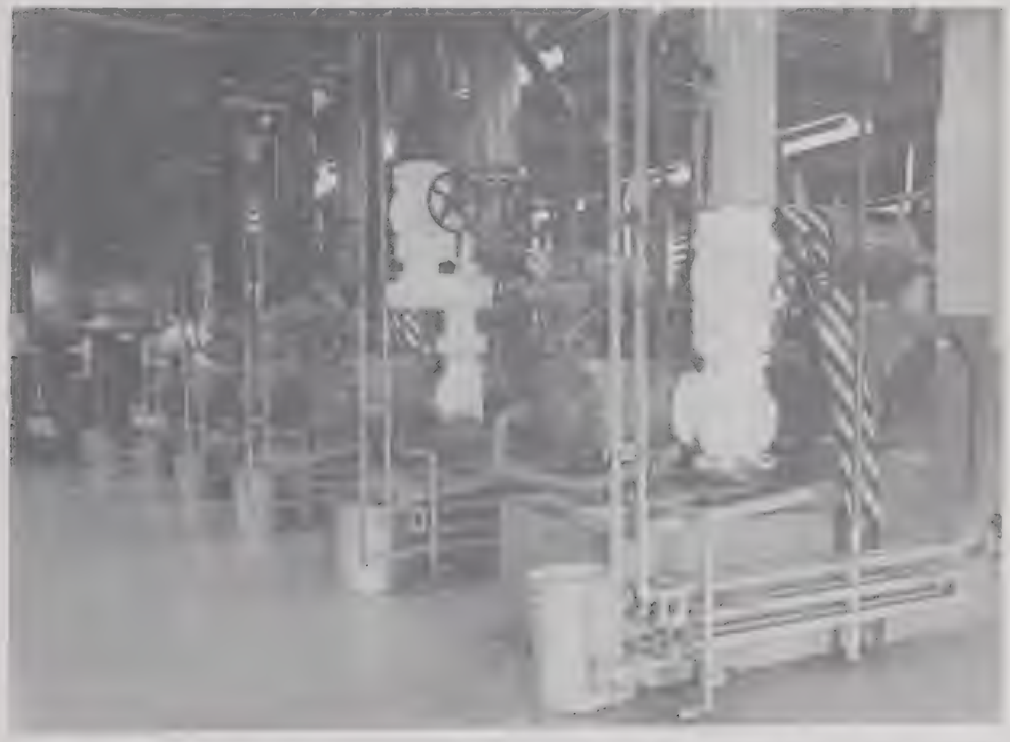
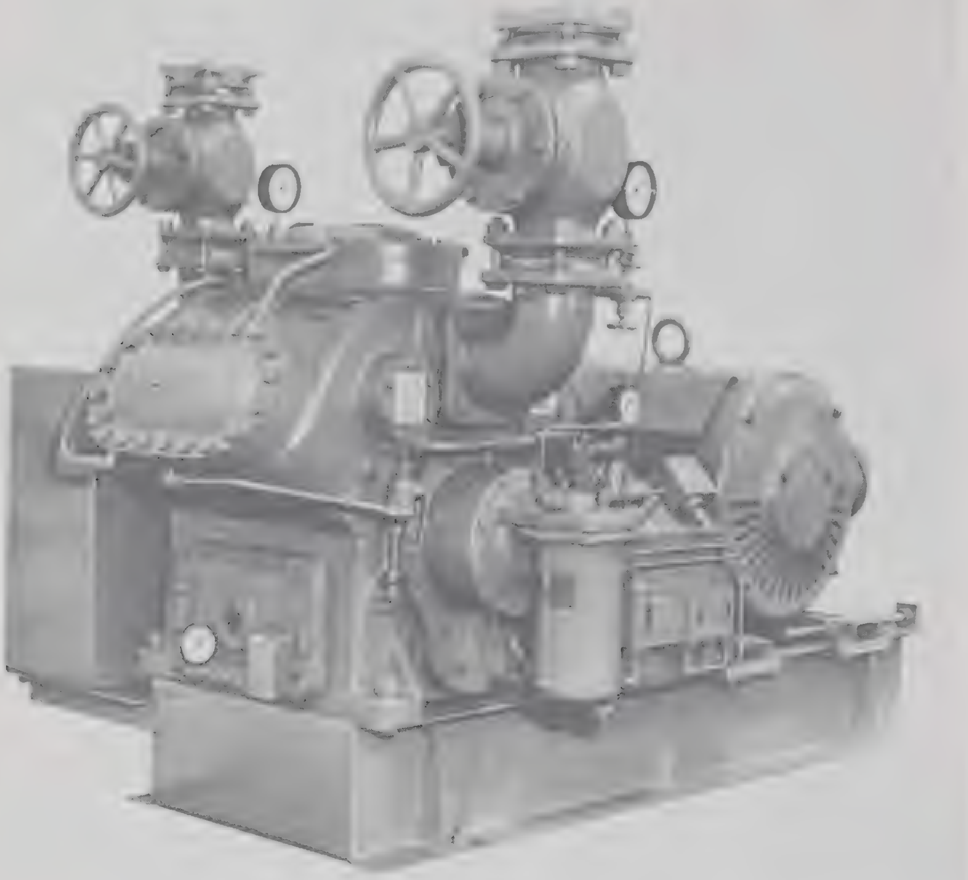


FIG. 11.5. VIEW SHOWING ROTARY BOOSTER COMPRESSORS IN SAME MACHINE ROOM AS HIGH STAGE COMPRESSORS—FIG. 11.4.



Courtesy Vilter Manufacturing Corporation

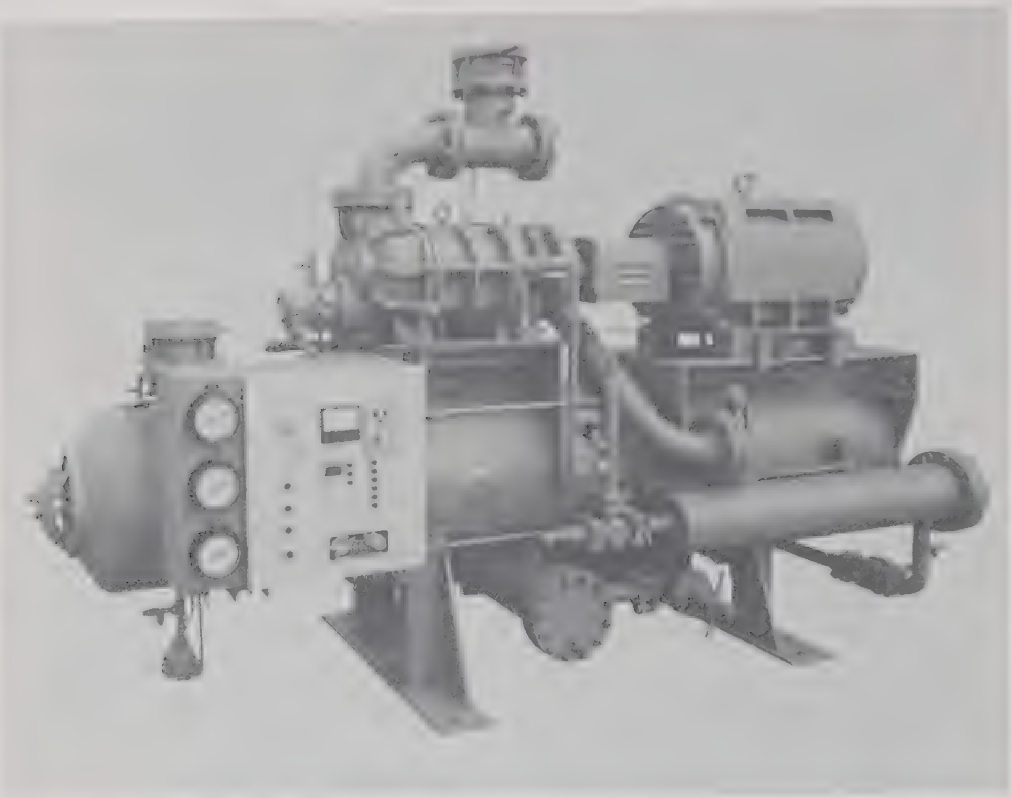
FIG. 11.6. MULTI-CYLINDER HEAVY DUTY COMPRESSOR SHOWN WITH DRIVING MOTOR AND ACCESSORIES ALL MOUNTED ON STEEL BASE. THIS TYPE COMPRESSOR AVAILABLE FOR AMMONIA OR HALOCARBON REFRIGERANTS.

When the halocarbons first came into use as refrigerants, large VSA ammonia compressors were quite often adapted to their application with rather indifferent success. Seals were a great problem to the ammonia compressor which has used packing in a stuffing box. This type of seal would not prevent leakage of the refrigerant at the shaft. Some valving problems also developed and this type of halocarbon compressor did not see much use. A number of fairly large VSA two and four cylinder compressors were developed with seals and valving for use with halocarbon refrigerants (mainly R-12 at that time). These compressors were used to some extent and also were altered for use as ammonia booster compressors and many of them saw more use as ammonia boosters than as halocarbon refrigerant compressors. As the smaller bore multi-cylinder compressors began to come more heavily on the market, they were adapted for both ammonia and halocarbon refrigerants. These compressors still represent a considerable portion of the market for both ammonia and halocarbon refrigerants in the medium to large heavy duty requirements of industrial use. A great number of cold storage facilities are now equipped with this type of compression equipment.

In the rather recent past, the screw compressor has come into favor for larger tonnages in industrial refrigeration. This compressor has been in use for a number of years as an air compressor and has recently shown increased popularity as a refrigeration compressor because of the addition in the late 1950's of an oil injection system which aided greatly in the sealing, cooling and lubrication of the compressor when used with a refrigerant gas. The screw compressor essentially consists of interlocking male and female spiral lobes so that gas entering at the suction end is compressed to the discharge pressure at the other end and discharged to the condenser. The injected oil is recovered in a highly efficient oil separator located in the discharge line so that excess oil is not carried out into the system. These compressors can be used through a wide range of pressures and may be used either as high stage or booster compressors and also may be used on either ammonia or halocarbon systems. To date, their best efficiency has been in relatively high tonnage capacities usually above 200 tons and 200 to 300 horsepower and up.

In larger installations, the screw compressor allows the use of halocarbon refrigerants in configurations not usual with reciprocating compressors such as flooded and recirculating refrigerating cycles. The screw compressor is becoming quite popular with large tonnage plants as it requires a minimum of floor space. Maintenance is not great and it would appear to be a long life machine. Noise levels of the screw machine were originally quite high. Considerable work has been done on the acoustics of the compressor to reduce the sound level to a more agreeable basis.

The rotary compressor has seen considerable use as a booster compressor, mostly in ammonia systems. This compressor consists of a rotor with axis off center from the main cylinder in which it revolves. Plastic blades ride in slots lengthwise in the rotor and move in and out to follow the contour of the cylinder as the rotor revolves. The plastic blades trap the entering gas and force it around to the discharge side, compressing it en route. This compressor works ideally as a booster in the range of 3 to 1 compression. The rotary compressor can be direct or belt driven as required at speed up to about 1750 rpm depending on the size of the compressor. Horsepower in common use may run as high as 150 to 200 as required.

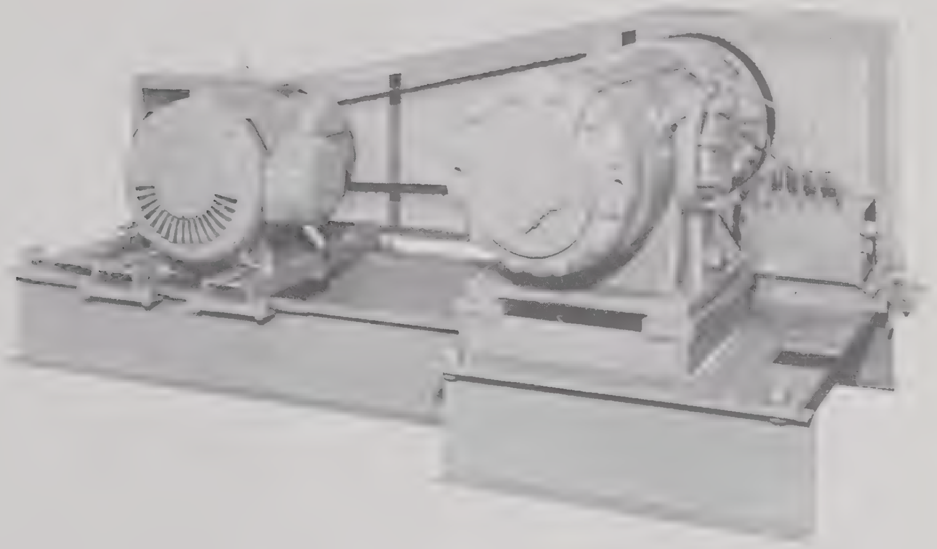


Courtesy Freezing Equipment Sales, Inc.

FIG. 11.7. ROTARY SCREW COMPRESSOR DIRECT CONNECTED TO DRIVING MOTOR. UNIT IS COMPLETE WITH OIL SEPARATOR, CONTROL PANEL AND OTHER ACCESSORY ITEMS.

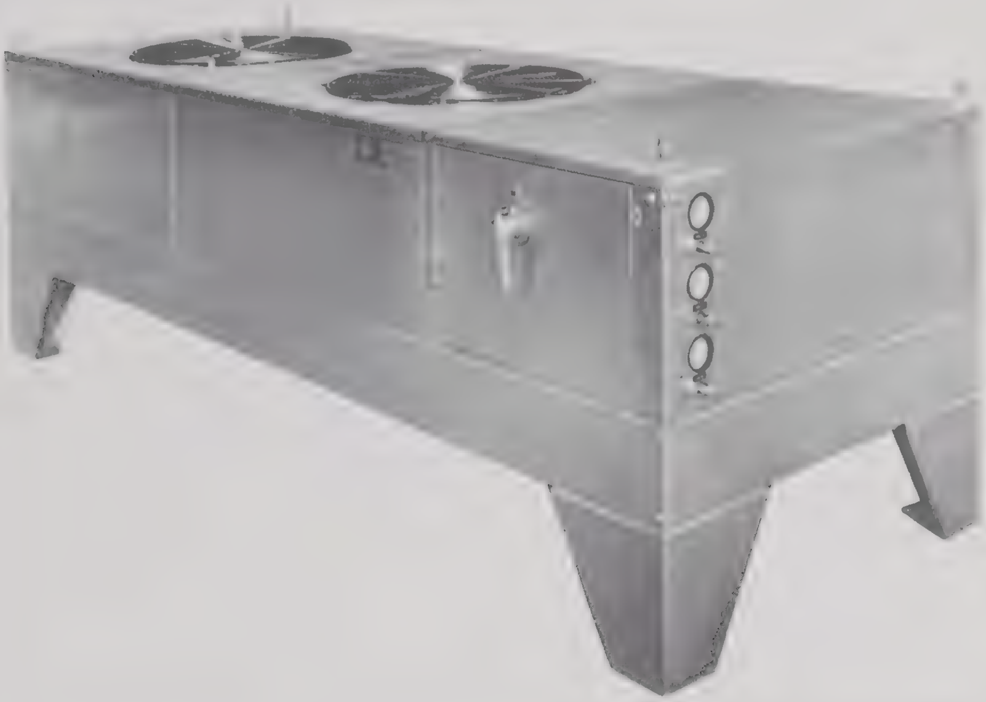
The semi-hermetic compressor has been developed for the halocarbon refrigerants and its greatest use has been in the commercial refrigeration field. This compressor with motor enclosed in the same casing is of lighter construction than the heavy duty types described above and the first cost is considerably less but life expectancy may not be as great. Great numbers of these compressors are being produced and used. Some use of them has also been made in the cold storage industry. Normally these units are equipped with air cooled condensers and, if not very carefully engineered with adequately sized auxiliaries, can use more power than necessary for a cooling job.

The constantly rising cost of labor and scarcity of competent personnel make automation of the modern cold storage a necessity. Automation is simplified in plants utilizing electric motors for supplying power to the various components requiring power. It should always be kept in mind



Courtesy Vilter Manufacturing Corporation

FIG. 11.8. ROTARY VANE TYPE COMPRESSOR USED COMMONLY FOR AMMONIA BOOSTER SERVICE. SHOWN WITH DRIVING MOTOR, BELT DRIVE AND BASE.



Courtesy Technical Systems Incorporated

FIG. 11.9. EXTERIOR VIEW OF COMMERCIAL AIR COOLED CONDENSING UNIT FOR OUTSIDE SERVICE. SEMI-HERMETIC COMPRESSOR WITH CONTROLS, AIR COOLED CONDENSER AND RECEIVER ARE ALL CONTAINED WITHIN UNIT.

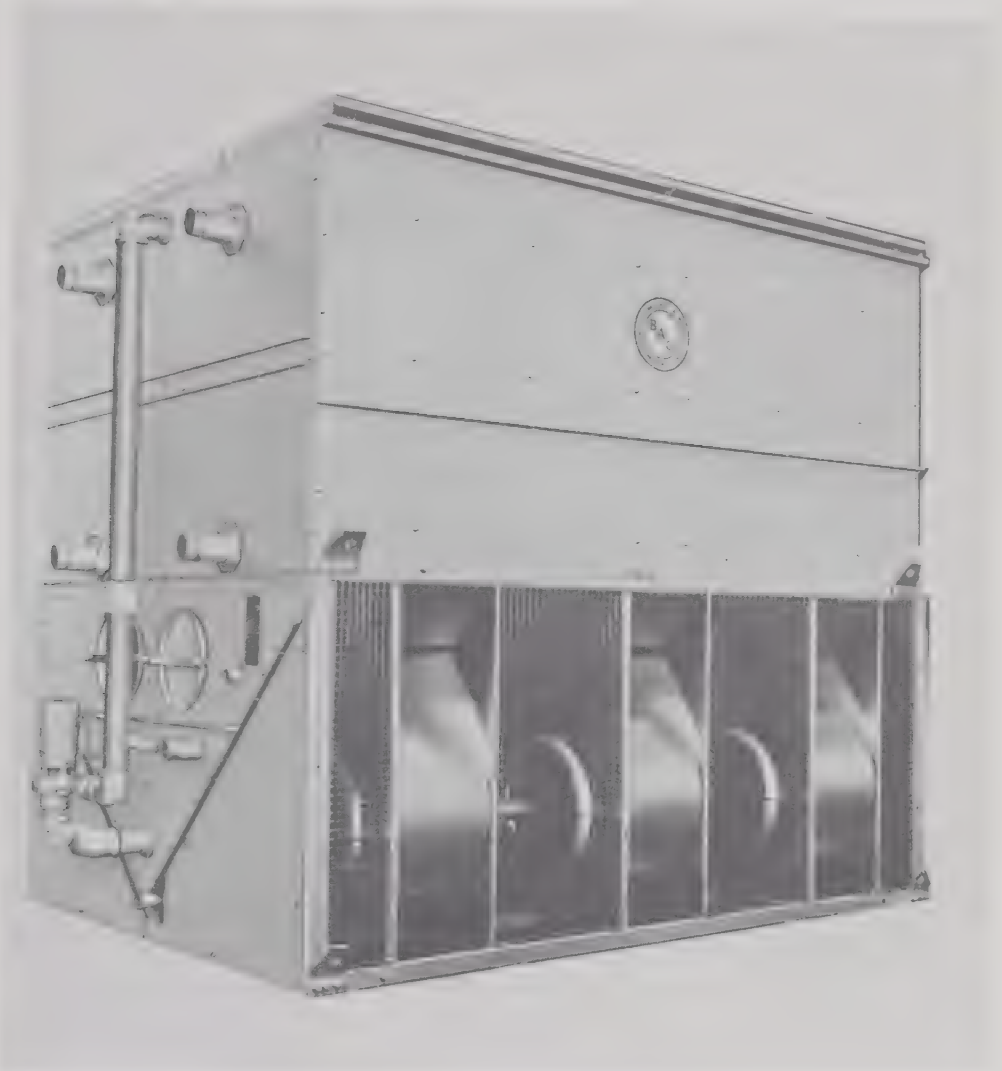
that a cold storage facility must operate continuously year round. For this reason, it generally will be found that heavy duty equipment, although having a greater first cost, will be justified by the longer life and longer maintenance free periods. Also that adequate or over-sized auxiliary equipment, such as condensers, may also be justified in the face of energy shortages and constantly rising power costs. Now, more than any time in the past, high efficiency leading to energy savings in any plant needs to be paramount in importance when considering the design of any plant requiring power to operate.

CONDENSERS

In large tonnage installations concentrated in a machine room, a water cooled condensing system or evaporative condensers will most often be used. Either method is satisfactory. Present designs seem to favor the evaporative condenser over the shell and tube condenser and cooling tower. The evaporative condenser is a somewhat more compact system than the condenser-cooling tower and is also favorable from a cost standpoint. Results are equal from either system.

In the shell and tube condenser, water is circulated through the tubes of the condenser. Figure 1.4 of Chapter 1 shows a view of a water cooled condenser. The water is directed back and forth through the tubes by the water heads which are baffled to direct circulation. The major number of condensers will be built for two or four passes of the water through the tubes. By this is meant that the quantity of water is pumped through one fourth of the tubes and turned back through another one fourth; back through the other tubes in two more passes. This would indicate a four pass condenser. The passes are arranged so that a water velocity is maintained through the tubes high enough to obtain good heat transfer. The water, after being warmed in the condenser by extracting heat from the refrigerant in condensing it into a liquid, is pumped to the cooling tower. The water is here sprayed, or allowed to fall over decking from the top of the tower to the basin. Air is forced into the tower against the water flow to cool the water. This is done by evaporation and the supply water is usually controlled by a float valve that maintains a proper level in the tower basin by admitting enough fresh water to offset that lost by evaporation and tower drift and bleed off. A centrifugal pump is normally used to circulate the water through the system. Condensers are normally used in multiple with one or two cooling towers.

In the evaporative condenser, instead of a shell and tube condenser, the condenser takes the form of a pipe coil and this coil is placed inside of a cooling devise similar to a cooling tower; thus combining a cooling tower with a condenser in one package. Figure 11.6 shows a typical evaporative condenser. In the evaporative condenser, the water is circulated from the basin of the condenser over the condenser coil through sprays, or troughs. The air is circulated over the condenser coil with the water flowing down over the coil. The heat exchange is somewhat complex but the end result, namely; condensing temperature of the refrigerant, is about the same regardless of the method used.



Courtesy Baltimore Aircoil Company, Inc.

FIG. 11.10. EXTERIOR VIEW OF EVAPORATIVE CONDENSER. CONDENSING COIL IS LOCATED INSIDE AT TOP. FANS AT BOTTOM CIRCULATE OUTSIDE AIR UP THROUGH COILS AND PUMP CIRCULATES WATER OVER COILS. SAME CONFIGURATION USED FOR COOLING TOWER WITH WETTED DECK REPLACING COIL PACKAGE.

Water cooled equipment is almost universally required on ammonia installations due to high temperature at the compressor discharge. In higher discharge temperatures, such as air cooled conditions, the temperatures are of a high enough order to cause oil carbonization and some breakdown of the refrigerant. In halocarbon refrigerants, the discharge temperatures are not as high as with ammonia and so air cooled condensers are sometimes used although not usually in high tonnage situations. Air cooled condensers are made in a variety of shapes and sizes. Essentially they consist of a condenser coil, usually made up of finned tubing, encased in a housing with propeller type fans or fans. Most installations utilize a fan blowing up. This tends to throw the hotter air upward, getting it away from the condenser and prevents recycling of the air. The vertical air flow is also independent of wind direction. Multi-fans are to be preferred in larger installations as fans can be cut out selectively during colder weather, thus saving some power. Figure 1.3 of Chapter 1 shows an air cooled condenser, typical of this type for industrial use.

In larger installations where either cooling towers and condensers or evaporative condensers are used, they should be sized for low head pressure (temperature). A typical example in an area with a 78° F (26°C) wet bulb temperature, the condensing temperature should not be higher than 95° F (35°C). This is about the lowest practical condensing temperature that can be achieved without the use of excessive equipment. The use of a desuperheat coil, particularly in ammonia installations is advantageous in that the temperature of the gas entering the main wetted condenser coil is lowered by the desuperheat coil and scaling tendencies are reduced. A desuperheat coil is usually a finned coil placed in the outlet of an evaporative condenser, above the water eliminators so that it will operate without being wetted and removes some of the superheat from the incoming refrigerant gas. Water should be constantly bled from the condenser system to prevent an excessive build up from solids left by water being evaporated in the condenser. In areas of good water supply, treatment may not be necessary where low condensing temperatures are held and adequate bleed off is maintained. In any event, bleed off will tend to reduce the amount of water treatment that may be needed.

Air cooled condensers are not generally used in larger installations except on unitized equipment using halocarbon refrigerants. Air cooled condensers should be adequately sized for as economical use as possible. A temperature difference of from ten to fifteen degrees F (5.5° to 8.3°C) between ambient air temperature and condensing temperature should not be exceeded for best operation with 15°F being the highest allowable and 10°F preferred.

RECEIVERS

Refrigerant receivers should be adequately sized to hold the refrigerant charge of the plant when possible. In some instances this may not be possible without an excessively large receiver or receivers. If an entire pump down is not possible, receivers should be adequate to hold the charge if individual parts of the plant are to be pumped out for any reason. Receivers may be paralleled without difficulty if kept at the same level and adequately equalized for pressure. Safety relief valves should always be provided on receivers and dual valves are required in most instances by code.

BRINE CHILLERS

Brine chillers used in cold storage operations are usually of the shell and tube type. Customarily, in the ammonia systems, the brine is circulated through the tubes of the brine chiller and the ammonia is introduced into the shell around the tubes. This is called a flooded type chiller. In halocarbon systems, the refrigerant is controlled by an expansion valve and is inside the tubes of the chiller. This is done for better control of oil return usually necessary in a halocarbon system. The brine is introduced in the shell and makes several turns around the tubes where it is chilled. Figure 2.1, Chapter 2, shows an ammonia type chiller and Figure 2.2, Chapter 2, shows a direct expansion chiller as used on halocarbon refrigerants.

At least two brine temperatures are normally maintained in a brine circulating plant which requires a minimum of two chillers at different temperatures. Usually, multiple chillers are desirable, both from a safety standpoint and from a control point of view. Multiple pumps are also desirable with a standby pump available for use in case of breakdown or maintenance of a pump.

Brine chillers should be adequately insulated to prevent excessive losses from the chiller. Pumps and lines should also have adequate insulation. Safety controls to prevent possible freeze up and also high liquid level and loss of brine pressure should be provided in addition to standard operating controls.

ACCUMULATORS AND INTERCOOLERS

Accumulators and intercoolers are important in any large plant and particularly in an ammonia plant. Suction line accumulators used with liquid return systems are valuable in both economical operation and as an insurance policy against machine damage. The purpose of an accumulator is to catch any liquid that may be returning from an over feed to an evaporator and prevent its passage to the refrigeration compressor where a slug of liquid could cause considerable damage. They are constructed as a pressure vessel with the internal volume sized to meet plant requirements. The diameter should be large enough so that the velocity of the incoming gas and liquid is slowed enough to allow separation of the liquid from the gas. The gas then returns to the compressor and the liquid is retained in the accumulator. It can be disposed of in several ways. In an intercooler-accumulator, a pipe coil is inserted in the accumulator and warm liquid from the receiver is passed through this coil on its way to feed the various evaporators in the plant. The warm liquid forms a heat load which evaporates the liquid in the accumulator which then returns to the compressor in the form of a gas. The liquid in the pipe coil is cooled which is, of course, an advantage in the operation of the plant. This form of intercooler is used, in some form, in almost all two stage plants on the intermediate suction pressure. System power is saved by cooling the liquid at a higher suction (less hp per ton ref) than low suction of the plant.

There are other systems designed to rid the accumulators of their liquid; some by pressure balances and others by means of refrigerant pumps pumping the liquid either back to the receiver or to some intermediate pressure where it may be utilized in the plant operation. Almost any logical system will work well if properly engineered for the job. Most accumulators utilize baffles in some form or other to prevent splashed liquid from returning to the compressors.

LIQUID REFRIGERANT RECIRCULATING SYSTEMS

A very excellent method of feeding refrigerant, where direct expansion is used, is by means of the liquid recirculation method. Refrigerant recirculation has been somewhat more common in ammonia plants than in halocarbon refrigerant plants but recent designs, particularly larger plants employing screw compressors, have used recirculation on halocarbon refrigerant systems with very good success. In the recirculating system, the refrigerant liquid is fed into a low pressure vessel, such as an accumulator connected to the suction side of the refrigerant load being served by the recirculation. As the high pressure liquid is metered to the low pressure vessel, the liquid cools itself down to the temperature corresponding to the pressure on the vessel by evaporating a portion of the liquid. The chilled liquid is then pumped to the evaporator units in the various storage rooms. Instead of boiling off all of the liquid in the evaporator as is done in an ordinary direct expansion of flooded unit, only a portion is evaporated, approximately 20 to 40% depending on the designers desire. Evaporation within the evaporator plus the excess liquid refrigerant flow through the evaporator tend to keep all surfaces within the evaporator wet with the refrigerant liquid. The wetted surface promotes better heat transfer than a partially wetted surface, such as found with a straight direct expansion coil. Control is also enhanced with liquid recirculation. Very high dependable evaporator performance also results. System controls can also be installed outside of the cold room.

The excess liquid returns from the evaporator to the low pressure vessel where it separates from the gas. The gas returns to the compressor and the liquid is recirculated along with new liquid from the receiver back to the evaporators where the whole cycle is repeated. Liquid flow to the evaporators may be accomplished by circulating pumps of several types designed and sealed for refrigerant pumping. It may also be accomplished by means of a pressure pumping system where a regulated highside pressure is used to force the liquid refrigerant through the low side units. In some of these systems the chilled liquid is isolated in relatively small pressure vessels and a controlled pressure from the high side of the system is used to force the liquid into the system. These small vessels are filled from the low side pressure vessel, then isolated and the controlled higher pressure applied to circulate the liquid. Alternating drums are often used with one vessel filling while the other is feeding the system. This assures a continuous flow of liquid to the evaporators. In either system, pump or pressure feed, the end result is the overfeeding of the evaporator units.

A simple solenoid valve in the liquid inlet to the evaporator unit is sufficient to shut off the flow of liquid for temperature control or defrost. Other controls are often used for more sophisticated control systems but the basic controls are concentrated at one vessel which is an advantage from an operating standpoint.

Somewhat larger suction and liquid lines are required for a recirculating system than for direct expansion since more liquid is circulated and the suction line must also carry some liquid in addition to the suction gas. Where pumps are used for liquid recirculation, a spare pump is an extremely desirable insurance against plant shut down from pump failure. Rotary, gear and centrifugal pumps are used for pumping refrigerants.

ECONOMY OF TWO STAGE PLANTS

The principal economy in two stage or booster plants is obtained by precooling the liquid refrigerant serving the low state evaporators at the intermediate or booster discharge pressure. Since this cooling is done at higher suction pressure, the cost per ton in horsepower is less and economy is effected. In a properly designed system, this economy can run from 10 to 15%. Intercooling requires the use of some type of vessel which also serves to chill the discharge gas from the booster compressor before entering the high stage compressor. For efficient and economical operation, liquid chilling should be a part of the system. Intercoolers should be generous in size with some reserve for future plant growth.

Two stage plants can show economy in operation through machine selection. Since compression is accomplished from suction to discharge in two stages, the compression ratio on booster and high stage compressors is less than in a single stage compression. This usually means a higher machine efficiency.

CONTROL IN WINTER OPERATION

Refrigeration machine rooms operating in cold climates usually will have adequate heating in the machine room to prevent freeze up of any equipment located in this room. External units such as cooling towers and evaporative condensers will require some type of winter protection. Ice formations can cause excessive weight and stress to a cooling tower and its supports. Forced draft towers are usually protected by operation of the fan keyed to the temperature of the pan water and also by bypass dump lines to prevent the water from flowing over the tower by bypassing it directly to the tower pan. This is best accomplished by automatic control.

Evaporative condensers are usually roof mounted. They do not normally contain a large quantity of water and can have freeze protection by use of an auxiliary tank located in the warm machine room. This tank is sized to contain the complete water charge of the condenser and during shut down, the entire water charge drains into the tank located in the machine room. During operation the water temperature is controlled by operation of the evaporative condenser fan.

Almost any plant will have exposed water lines in and about the installation and normal precautions should be taken to prevent freeze up of these lines.

PROVISION FOR GROWTH

Any successful cold storage operation may expect to grow as the operation continues. Growth is inevitable with a successful operation and this fact is too often ignored in the original design of a refrigeration plant for cold storage operations. It is relatively easy and inexpensive to add some features to the design of a system to allow for future growth and certainly a great deal less expensive to design for future growth than let it catch the owner with no extra capacity potential.

Where a central machine room is utilized for a plant, accumulators can be made oversize as well as some of the headers and piping for future loads. A few strategically placed valves can serve to accomodate new additions without shutting down operations. It is also important to allocate some space for future machinery and other plant requirements so that expansion can be in an orderly manner not a hodge podge of machinery, unrelated in function and operating with only mediocre results.

Provision for future requirements can only be carried so far. Who knows what systems may be developed in the coming years and there is a real possibility that refrigeration concepts and necessities may change radically over the coming years. The prudent plant owner will, however, make provision in a new plant for all the expansion he can foresee in the coming years and hope that this provision will, at least, serve as an orderly basis for whatever expansion may be required. A master plan is not amiss in the design of a warehouse with an outline of requirements and future placement of equipment in whatever steps seem prudent. This type of planning can save a lot of misunderstanding and poor design in future years.

EVAPORATORS IN COLD STORAGE

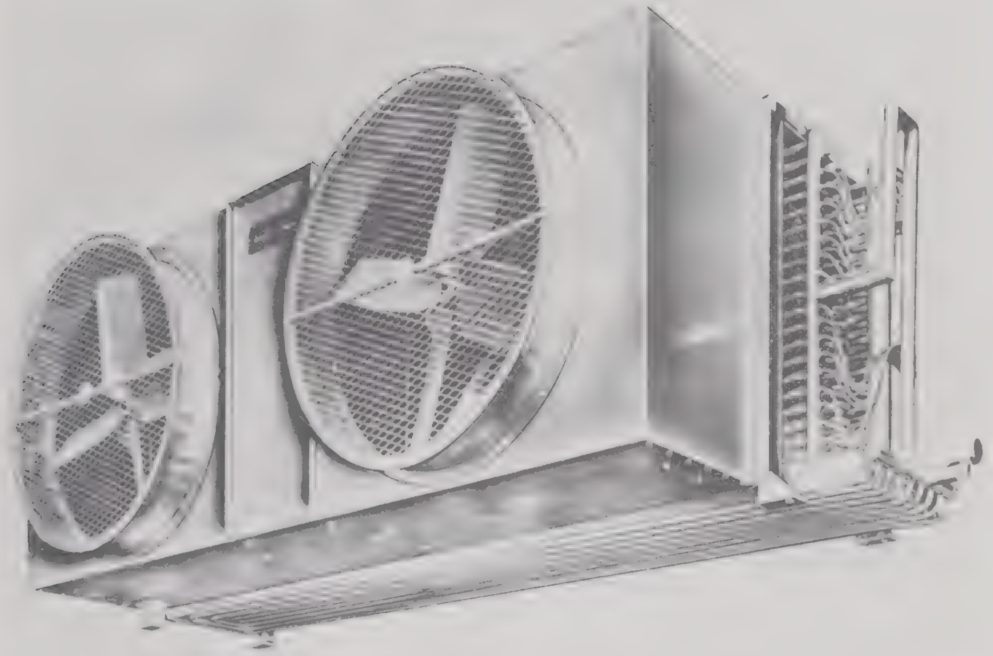
Evaporators in various storage rooms are, at present, confined in most instances, to a type of forced air unit which may be either floor or ceiling mounted. Coils of bare steel pipe hung along walls or on the ceiling are still used to some extent in older installations but other than this have been largely abandoned and not used in new installations. These coils were heavy and cumbersome requiring special supports or roof bracing to hold them. First cost was high and defrosting always a problem.

A typical ceiling of floor type evaporator consists of a cooling coil properly headered for refrigerant feed, or for brine circulation in an indirect system. The coil is normally of finned construction with the fins added to the bare copper or steel pipe to materially increase the amount of surface exposed to the air. In the case of steel coils, the fins are usually also of steel and the whole finned coil assembly is hot dipped galvanized after fabrication. In the case of copper coils, aluminum fins are usually mechanically bonded to the coil. Coils are occasionally fabricated from other metals but copper and steel hold a favored position in the manufacture of cooling coils. Fin spacing will vary from as low as 2 or 3 fins per inch to as high as 6 or 8 depending on the temperature at which the coil works and the manufacturers design. Normally, the lower temperatures require a wider fin spacing so that frost does not block the space between fins readily. As temperatures go above freezing, closer fin spacing may be used since frost is no longer a factor and more surface may be compressed into a given space with more fins per unit length. The coil is held in a casing which also supports a fan and the fan either can blow through the coil and out into the room or the air may be pulled through the coil by the fan and then blown into the room. A drain pan is located beneath the coil to drain away the condensate from the coil for above freezing applications and the defrost water from defrosting in below freezing temperature rooms. Drain pans are sometimes insulated and sometimes also heated to prevent freezing of any water that may be in the pan during defrost.

Ceiling type units will usually be equipped with propeller type fans blowing out into the room with no duct work. Occasionally a centrifugal fan may be employed where duct work is required with static pressure needed for air circulation or some other need may require an external static pressure on the unit. Experience has shown that a number of ceiling coils placed along one side of a room, all blowing across the room, will enhance the circulation of air in the room. As the number of units is increased the air in the room tends to maintain motion in the direction set by the unit fans and as the number of units in a room is increased for larger rooms, a distance of 100 to 150 feet may be air spanned by units without duct work and with resultant even air temperature and flow. The mass of the entire quantity of room air circulating in sympathy with the unit air flows creates a very good air flow pattern.

In ceiling units blowing directly into a room with low static pressure required, the propeller fan is most often used since it is more efficient and less expensive to build. Fans may be direct connected to the shaft of a motor or belt driven depending on the size of the blade and the horsepower involved. The larger units usually employ larger slower speed fans than the smaller units and require a relatively slow speed motor for direct connection or a standard motor for belt drive. Quite often the smaller unit will use a special motor to obtain certain configurations of the unit. It is good practice, where a number of special motors are involved, to determine the availability of such motors for replacement purposes and if a standard motor can be used, if the special motor is not available, without too much difficulty in adapting the unit to accept the standard motor. In larger units where belts are used, a standard stock motor is normally used.

Good practice in units, particularly in freezer operation, is to use units with fan or fans, mounted to pull air through the coil and discharge it into the room. There are also some advantages to using such a unit in cooler rooms. With a fan blowing air through a unit in freezer operation, the warmer air passes over the fan blade first. In instances where a coil may be located close to an outside entrance to a room, moisture laden air



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Courtesy Bohn Heat Transfer Division

FIG. 11.11. CEILING TYPE COIL EQUIPPED FOR HOT GAS DEFROST SHOWING HOT GAS COILS UNDER DRAIN PAN FOR WARMING DURING DEFROST. USED IN FREEZER ROOMS.

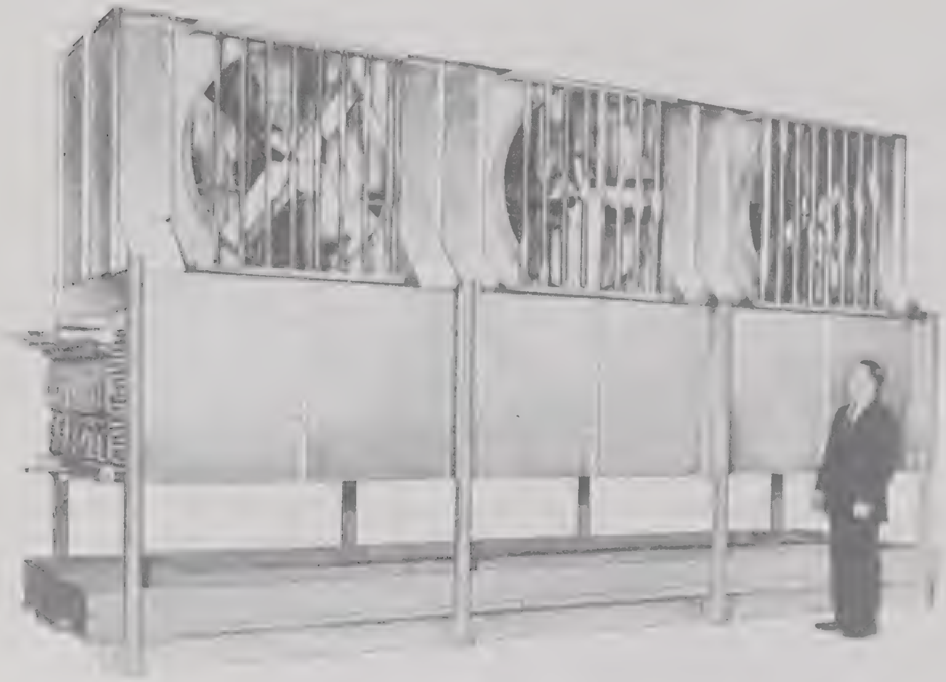
can pass over the fan and some ice may accumulate on the blade which can cause an imbalance of the blade with sometimes destructive results. If the air is first passed through the coil, most of the moisture will freeze out on the coil rather than the fan blade.

Floor type units are usually somewhat larger in size than the ceiling type and fewer units will normally be used per room. The floor unit consists of a coil and fan or fans mounted above a drain pan and all encased in a suitable housing. Centrifugal fans are almost universally used since the air is conducted up to the ceiling level of the cold room and spread at a 90 deg. angle for room coverage. Air entering the floor unit must make a 90 deg. turn into the fan. This all imposes resistance to the air movement and the centrifugal fan is more able to overcome this resistance economically than the propeller type. The floor unit has the advantage of being accessible for maintenance and repair readily. It has the disadvantage of taking up valuable air space that could otherwise be used for merchandise storage. It is also, unless heavily guarded, subject to mistreatment by materials handling equipment. Fewer larger floor units are usually required with less piping and lower installation costs. This is usually offset by higher costs per unit capacity of the floor type unit.

Sizes of units vary widely. Ceiling units are usually readily available in sizes up to 20 to 30 tons capacity and floor units are manufactured in ratings up to 40 tons and higher depending on the manufacturer.

EQUIPMENT FOR SPECIALIZED FREEZER ROOMS

Sharp freezers, blast freezers and other specialized freezer rooms will quite often utilize special fan coil units designed to do a specific freezing job. Commercial freezing units are available and are utilized as well as built up systems tailored to a specific condition. It will be found generally that sharp, or blast freezers for public warehouse purposes should not be too specialized in design, but rather be designed to handle a variety of products. In this day, blast freezers and freezer tunnels can be used for multiple operations and kept busy a greater portion of the time. The most common type of freezer in most warehouses is probably the blast type. These freezers are fabricated in any number of ways to suit individual designer and owner desires but generally consist of a bank of



Courtesy Rigidbilt, Incorporated

FIG. 11.12. BLAST FREEZER UNIT FOR BLASTING LARGE QUANTITIES OF AIR OVER PRODUCT TO BE FROZEN.

coils installed overhead with large fans delivering large quantities of air over the coils and down into a small room, or tunnel, below in which the product to be frozen is stored. The enclosure, or freezing tunnel will usually be relatively small with doors at the sides or ends for loading in merchandise and which can be closed during the freezing cycle. In larger warehouses, there may be several such rooms depending on the location of the facility and the amount of freezing required. Very specialized freezing is not usually handled by the cold storage warehouse but rather by the processor in his own plant. Products frozen by a warehouse are not normally critical as to freezing time or temperature. The main advantage of the tunnel type freezer is saving in space. High cold air velocities over the products tend to freeze them rapidly, thus allowing the product to be placed in storage in a relatively short time and the freezer returned to freezing use. By freezing before storage, spreading of product in a regular freezer room is spared and handling is minimized and space is conserved. Higher product concentration in the freezer rooms is achieved by palletizing and stacking the frozen products and storing without additional handling. This aids in increasing the room revenue.

Blast freezer tunnels are maintained at from about −10°F (−23°C) to as low as −40°F (−40°C). Many products such as liquid eggs, boxed meat, carcass meats, etc., can be frozen in a blast freezer. The blast freezer is a useful aid in a warehouse, particularly if the warehouse is working at near capacity storage loads. Its main use is conservation of space required to freeze. There are some product improvements in blast frozen products but these are not really significant, particularly in the products normally handled.

Some warehouses may contain specialized freezing equipment for products critical to freezing time and temperature. These freezers are usually constructed on a lease basis, or some pay back basis, for a specific customer and to his specifications.

Most blast freezers will contain direct expansion coils of one type or another. Lower temperature requirements do not usually encourage the use of a secondary refrigerant for this application. Liquid recirculating systems work quite well and are frequently used in blast freezers. Flooded ammonia feed is also used rather extensively. At lowered suction temperatures, line losses from pressure need to be minimized and short lines are desirable as well as lines adequately sized. Because of the desirability of minimum suction line pressure drop, blast freezers are often installed adjacent to, or close by the machine rooms. This is almost a necessity in the case of halocarbon refrigerants. In ammonia systems pressure drop may be minimal regardless of length but size of lines must be increased to achieve this. From suction line cost the advantage of short lines is apparent.

WINTER OPERATION

Winter operation control of refrigeration plants is always a problem. There is the problem of below freezing temperatures and the attendant frozen pipes, etc., in and about the plant. There is also the problem of cold weather operation of the refrigeration plant itself.

For freezing temperatures, a regular procedure is needed to shut off exposed water lines that are exposed to the cold outside conditions. This applies to all lines around the plant and not to the machine room alone. Inadvertently, some lines are usually neglected and so provisions should be made for prompt repair or replacement of frozen lines and equipment. A minimal stock of water valves and pipe fittings is a good investment for just such occasions.

Operational cold weather problems can be of some magnitude unless proper attention is paid to them in the design of the plant. In climates where winter time freezing weather can be expected, evaporative condensers can be placed so that their sump or drain tank is dropped into a machine room or heated area so that all of the water will drain to an above freezing space when the condenser is shut down. Cooling towers, when used, should have provisions made for dumping return water directly into the basin during extremes of cold weather to prevent freeze up. During milder weather, operation without the fan operating may be sufficient to prevent any freeze up.

In areas of prolonged cold weather, some precautions may need to be taken to prevent cooler rooms from dropping to too low temperature and some type of heating may be required in these instances. If dry storage is a part of the operation, some type of heating will almost always be required except in the very temperate zones of the country. As energy costs increase, the value of insulation, even in dry storage rooms may become more apparent. Many of the old rules of power costs vs. insulation pay out will be in need of revision, if they are not already outdated.

Ice accumulations on docks and other parts of the warehouse are all items that need to have some thought as to what to do before they actually occur. Continued warehouse operations is a necessity and areas need to be kept accessible at all times.

Cold weather also means specialized operation of refrigeration machinery. There are many schemes and devices on the market, many which waste power by artifically holding up compressor discharge pressures to maintain evaporator operation without altering some of the operating devices for feeding the evaporators. Valves are on the market that will permit relatively large swings in head pressure and still maintain proper feed to the evaporators. Multiple expansion valves used selectively can also be used as power savers by allowing head pressures to sink to relatively low levels without disrupting service. In the interest of saving power, devices should be installed and used that will allow head pressures to operate at low levels during cold weather. Some compromises are probably necessary but considerable thought should be devoted to cold weather operation when the initial design of the plant is considered.

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Systems

Almost any warehouse will have a combination of several types of refrigeration systems incorporated in its overall operation, particularly if the plant has had additions made to the system over the years. Normally, one system will prevail and this one will usually be the original system installed except in the case of a complete rebuild of a plant. Various systems are to be discussed but it should be remembered that bits and pieces of many systems may exist in the same plant and may be operated harmoniously into a complete satisfactory mixed system.

EVAPORATOR AND CHILLER UNIT FEEDS

Before considering a complete system, a review of the various ways of handling the end product of the refrigeration system, the evaporator or chiller unit, should have some study. There are several ways of controlling the admission and circulation of a direct and indirect refrigerant in a room cooling coil. Some of these will work well in one circumstance and not at all in another. A review of this is then probably in order as a preliminary to system description.

DIRECT EXPANSION EVAPORATOR

The direct expansion evaporator is an outgrowth of the very early pipe coil evaporator which used a hand valve to expand and drop the pressure of the refrigerant and feed it to the coil in the proper amount so that it would be completely evaporated in the coil and emerge as a gas at the coil outlet. Over the years the pipe coil has fallen into disuse and has been replaced by the forced air finned coil which, of course, is compact and requires little space. The hand expansion valve has largely been replaced by the thermal expansion valve which performs the same function as the hand operated valve but does it automatically by means of sensing the outlet temperature of the gas in the coil. By maintaining a constant differential between the refrigerant temperature in the coil and at the outlet of the coil, complete evaporation is assured with a resultant dry gas to the compressor. This type of feed may be used for either ammonia or halocarbon refrigerant coils with equal success. In larger installations, the halocarbon systems will utilize this type of feed more frequently than the ammonia systems where a wider variety of feeds are successfully available. The direct expansion feed is simple and reliable. It does not utilize the entire coil for cooling as well as some other types since part of the coil must be used to warm, or superheat the gas, to maintain the proper differential. Therefore, this part of the coil does little cooling. It may amount to as much as 5% or more of the coil surface. The direct expansion coil, when properly installed will assure an adequate oil return in the halocarbon system. Oil return in an ammonia system is usually of little concern since oil is drained at the coil rather than returning it to the compressor.

FLOODED EVAPORATORS

In the flooded type evaporator, the liquid refrigerant is fed into an accumulator, or refrigerant drum above the evaporator where the pressure of the refrigerant is reduced to drum pressure which is essentially the same as that in the evaporator. The cold liquid refrigerant then flows by gravity into the evaporator coil below where it is evaporated by the heat being carried to the coil from the room. The liquid refrigerant travels all through the coil, boiling as it travels so that at the outlet of the coil will be found a mixture of liquid and vapor traveling together. Any liquid droplets carried out of the suction of the coil are deposited in the accumulator and back to the coil since the suction of the coil dumps into the accumulator. The gas is then drawn from the accumulator to the compressor and the liquid stays in the drum. This type of system operates somewhat more efficiently coil-wise, than the direct expansion system as the coil is better wetted on the inside by the refrigerant and almost all of the coil is utilized for the transfer of heat. Liquid level in the accumulator is maintained by means of a float valve or float switch and solenoid valve. Flooded systems are used mainly with ammonia systems since oil return is not a problem and oil trapped in the accumulator is drained out periodically as required. Flooded systems have been used in halocarbon systems but have not proved too popular due to oil return difficulties. Considerable trigger work is required to return oil from this type of system in halocarbon systems. Its main use is therefore, with ammonia systems.

RECIRCULATING REFRIGERANT FEED EVAPORATOR

In the recirculating refrigerant system, the refrigerant liquid is expanded and chilled (by lowering its pressure) in a low pressure vessel called either a low pressure receiver or accumulator. The pressure is maintained in this vessel at the same point as the pressure in the evaporators. Liquid refrigerant is pumped by means of a mechanical pump to the various evaporator units in the plant. The flow of refrigerant is regulated into each unit by means of a regulating valve which is set to maintain a definite ratio between refrigerant circulated and refrigerant evaporated. This can vary depending on conditions and the refrigerant used. Normally, in halocarbon systems, 2 or 3 times more refrigerant is pumped to the coil than is evaporated by the coil. In ammonia systems this ratio may vary from about 3 to 5 or 6 times as much refrigerant circulated as evaporated. The effect of the refrigerant circulation in excess of that evaporated is that the interior, or refrigerant side of the coil, is completely wetted by the liquid refrigerant and flow is somewhat turbulent due to evaporation of some of the liquid. This all leads to a high transfer rate of heat flow and a highly efficient coil. The excess liquid flows back through the suction line to the low pressure vessel where it is separated from the refrigerant gas and the gas returns to the compressor.

A second form of the liquid refrigerant recirculating system utilizes refrigerant gas at condensing, or high side, pressure to force the flow of liquid refrigerant to the evaporators instead of a pump. By means of various pressure regulating valves, solenoid valves and controls, refrigerant liquid from the condenser is combined with liquid returning liquid from the evaporators in a pressure controlled vessel and the imposed pressure on the vessel is sufficient to feed the liquid to the various evaporators. This is an intermittent system and is often made continuous by pairing certain vessels to achieve alternate feeds for continuous operation. Mechanical pumps are eliminated but there is added maintenance of valves and controls.

The recirculation system works extremely well with ammonia and is seeing some use with the halocarbon refrigerants, particularly larger systems using screw type compressors where oil return is not the problem that it is with reciprocating compressors. Controls may be placed outside the cold room and can be centralized in some installations which is an advantage. Controls are also simple and the system lends itself well to hot gas defrost.

BRINE CHILLER UNITS

Room cooling units designed to work with brine are similar in appearance to those operating on refrigerants except they are circuited to allow the passage of solid liquid through the coils with no evaporation. Chilling of the air passing over the coil is accomplished by warming the brine flowing through the tubes of the coil. Brine flow is controlled by means of automatic valves either shutting off brine flow or bypassing it around the coil. This can be modulated for accurate control. Many different schemes are used in brine systems for control of various temperatures. Where a remote cooler room is desired and only low temperature brine available, a blending pump may be used to recirculate a mixture of the very cold brine from the brine chiller with warmer brine returning to the chiller from the coil. This blending can produce a warmer brine for warmer rooms and help prevent severe product drying. This is not advocated for large areas but where a small tonnage a long ways from the machine room or warmer temperature brine, is required, it can be used to good effect. Where accurate humidity control is desired, blending of the brine can also be used effectively.

Defrosting of brine coils in freezer rooms can be accomplished in several ways. Water defrost can be used effectively by shutting off the brine flow to the coil and allowing the defrost water to flow over the coil. Fast draining of the drain pan is required in water defrost to prevent freezing of the water before being drained out of the room. Warm brine can also be used to defrost by flowing it through the brine coil. In large plants, this requires a warm brine line to be installed since it is usually not practical to defrost all units at the same time. A third alternative is electric defrost utilizing electric heat to warm the coil to melt off accumulated ice. This requires installation of electric lines of some amplitude to the various units and also power consumption to defrost.

CENTRAL MACHINE ROOM

The central machine room where all of the refrigeration machinery with the exception of the evaporators has, over the years, been the approach most often used in the cold storage industry. This has been almost universally true with the use of ammonia plants which have been predominate in the cold storage field over past years and particularly in the larger houses. Recent construction has tended to refute this statement to some extent but the central machine room probably still holds favor as a desirable way to provide refrigeration.

In ammonia plants, direct expansion evaporators, or flooded or recirculated types are readily usable even at considerable distances from the machine room. With no oil return problems, suction lines can be sized strictly from the standpoint of desired pressure drop and very low pressure drops may be designed into the lines. This is an advantage for efficient operation. With proper selection of compressor sizes, automation is easily achieved regardless of the size of the plant. Cross connections of compressors to serve on more than one refrigerant temperature and with a spare machine or two, makes a plant that has redundancy without great expense and a plant that it is very difficult to founder. Machines may be switched from one load to another as conditions warrant. Machines can also have down time for maintenance or repairs without affecting the plant operation. The central machine has many arguments in its favor, particularly in ammonia plants. Concentration of the refrigeration high side equipment can cut down on the number of watch engineers on duty and make some labor savings. Also repairs are more or less concentrated in one area which can cut down on the number of maintenance personnel required since their efforts are pretty well confined to one area. This shortens travel time and set up time. Most large machine rooms will have a crane or boom set up whereby heavy parts can be managed without too much physical effort.

Recent designs in central machine rooms for large plants have included some utilizing halocarbon refrigerants with screw type compressors. Oil return and oil recovery for the screw type compressor is somewhat different than for a reciprocating type, most of the oil being recovered at the compressor rather than being allowed to circulate. In plants employing hot gas defrost, any oil circulated and settling in evaporator coils will be returned during the defrost period. This is a factor that is true for both ammonia and halocarbon plants. Returned oil in ammonia systems is trapped out before reaching the compressors. Refrigerant circulation also can be used with the screw compressor, and halocarbon refrigerants will give a very good operation efficiency. The halocarbon refrigeration plant probably would not be as workable as an ammonia plant on extremely long runs but by the use of liquid recirculation and other means can reach out a respectable distance. The halocarbon central machine room is a definite possibility in large plants employing screw compressors.

Where reciprocating compressors are in use, the halocarbon refrigeration plant has some shortcomings. Long suction lines need to be carefully designed to permit oil return or rather elaborate devices must be provided. Design is somewhat critical and sizing needs to be exact. Some difficulties can be experienced in multiple use of halocarbon reciprocating compressors. Not too many plants of this type are being designed at present. This is not meant to imply that a large plant with reciprocating compressors and long lines cannot be designed, but that the design is more exacting and more problems can arise than with a screw compressor on halocarbons or ammonia refrigerant, or with an ammonia plant with reciprocating compressors.

In an indirect plant circulating cold brine to the various cold rooms, almost any refrigerant and compressor combination can be designed for effective use. In this type of plant, all of the refrigeration equipment is confined to one area. Refrigerant lines are short and designs are somewhat simplified over the direct expansion plant, particularly in the case of the halocarbon refrigerants. Multiple machines are of advantage the same as in the direct expansion plant. Brine chillers are usually of the closed shell and tube type and are used in a closed system with circulating pumps. Normally, brine chillers will be supplied for two or three temperatures as required by the plant operation. The main advantage of this type of plant is the containment of all of the refrigerant in a single area. Close control can be maintained in cold rooms with relative ease.

Difficulties encountered in a brine circulating plant are the fact that due to the double heat transfer (refrigerant to brine and brine to room) a lower refrigerant temperature must be maintained than with a direct expansion plant. This is costly from a power standpoint. Also the horsepower of the brine pumps must be added to the power comsumption of the plant making for a somewhat higher power cost. Brine lines must also be well insulated both on the supply and return side to prevent undue heat loss from these lines.

Some products, such as pecans, when exposed even to a mild ammonia leak can darken in color and lose in grading. Because of this, these few products so affected are quite often supplied with refrigeration from a small brine chiller or by halocarbon refrigerants. Where a selected area only is to be chilled by brine, the brine chiller may quite frequently be located away from the machine room and close to the cold rooms served which serves to give somewhat more efficient operation.

In a large plant, modification of the central plant can lead to more efficient and probably better operation. The modification could consist of more than one central type plant, each of sufficient size to afford redundancy of machines and safety of operation from a shut down standpoint but serving a smaller area so that extreme length lines would not be required. This type of machine room could prove particularly advantageous in the very large and long cold storage plant. As an example, a plant requiring some 1200 tons of refrigeration could very easily be split into 3 machine rooms of 400 tons each or two 600 ton machine rooms. These smaller sub-central rooms would still be large enough to operate at maximum efficiency but suction line distances in the plant could be shortened with better operation and smaller lines. Also future additions could be managed easily by additional sub machine rooms. In the 300 or 400 ton machine room, one spare machine could be provided for cross connecting use or peak loads. If desired, the various machine centers could be cross connected for emergencies, but should not be connected with expectation of using these lines for anything but emergency use. In case of a disaster, such as a fire or tornado damage, one or more of the machine rooms would probably survive for at least partial service. Either ammonia or halocarbon refrigerants could be used for these smaller machine rooms with about the same restrictions as for the larger single machine room. Screw machines would probably need to be used in a room of 400 tons or better to utilize more than one compressor efficiently. Booster machines could be in the form of screws, rotary or reciprocating type depending on the designer of the plant.

Since almost all cold storage plants need to show growth to survive in a competitive market, the smaller automated refrigeration machine room, utilizing two or three such installations in the plant seems to offer a good solution. As space is added, machine rooms could also be added for the additional load. These rooms should be placed for easy access from ground level, either at ground level or possibly on a mezzanine deck above a work space but still easily reached by operating and maintenance personnel. Condensers could be roof mounted above each machine installation. This type of construction would seem to give all of the advantages of efficient operation inherent in a larger plant plus additional advantages of shorter lines, and redundancy of refrigeration equipment. In highly seasonal storage areas, certain areas of the plant including machine rooms could be shut down during the off season. This would not occur in many areas but would be an advantage where partial shut downs are effected during certain seasons of the year.

INDIVIDUAL UNITIZED EQUIPMENT

In recent years, a great number of smaller systems have been developed where the refrigeration compressor with its condenser is roof mounted with the cold room coil suspended in the cold room directly beneath the condensing unit. Cooler systems as well as freezers with hot gas defrost have been developed and used in a variety of situations. Capacities of these systems can range from 5 tons and under to upwards of 30 or 40 tons depending on the application. Almost without exception the units utilize halocarbon refrigerants and air cooled condensers. Compressors used are mostly of the commercial class, the majority probably being of the semihermetic type. Individual systems can, of course, be tailored to suit with heavy duty industrial condensers and evaporative condensers can be supplied if desired. However, the greatest number are standard with air cooled condensers and semi-hermetic compressors. The units are versatile and it is usual to install several in a single larger room to give constant service in the event of failure of an individual unit or two.

The unitized equipment can be used with considerable success, particularly in existing plants where a remote area is to be refrigerated and line from the central plant would be expensive or where the central plant is overloaded. The unitized equipment does not take up any plant floor space since it is normally roof mounted. This argument is balanced by the fact that the unit may tend to lack service since it is out of the way and sometimes difficult to get to. Compressor changeout, when required, is difficult in larger sized motor compressor units which are difficult to handle and must be lowered from the roof. No central engine room space is required for these units but there are, in effect, numerous small roof machine rooms that should be attended regularly for proper maintenance. Oversized air cooled condensers are sometimes used on these units to promote efficiency and this should be a requirement whenever they are installed. Evaporative condensers, except on large units, can be grouped. An evaporative condenser can prove advantageous, particularly if sized for lower than standard halocarbon conditions; i. e., 95° F (35° C) condensing with 78°F (25.5°C) wet bulb temperature. This could be particularly true if air cooled condensers are located where air entering has been superheated by traveling over a large sun exposed roof area. Winter operation would need special design with an evaporative condenser.

Each cold storage presents a separate design problem and a careful design needs to be worked out for the plant utilizing the equipment best suited to that plant whether it be a central machine room, multi-machine room or combination with central and some remote type units. The mix should be carefully analyzed, now more than ever before, as to power costs for operation as well as maintenance costs and first costs. With energy shortages and high power seeming to be almost a certainty, it would seem that low operating cost and high efficiency of the plant need to be the determining factor. Lowest first cost would not appear to be the best criteria by which to select an installation in view of the factors that now face the owner of a facility.

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13

Control Components and Measuring Elements

In any cold storage operation, there are certain measurements that need to be taken to properly evaluate the operation of the refrigeration equipment. A great many of the control and measuring elements are common to all refrigeration installations and some of the major ones will be discussed in this chapter. Many brands of both operating controls and measuring instruments are on the market today and most of them are reliable in operation. Good controls and accurate measuring devices are not cheap but are necessary to operate a plant in an economical and efficient manner. They are a good investment in an era of expensive power and energy scarcities in that they can indicate proper operation to achieve the greatest efficiency.

TYPES OF INSTRUMENTS FOR OPERATION

A refrigerating plant must be provided with sufficient instruments to indicate the operation of all parts of the plant if the operating engineer is to know how the overall plant is functioning as well as the individual components. Without proper instruments, the operating engineer must guess how various parts are functioning and, as a result, inefficient operation is often tolerated through ignorance of reliable data. Instruments are costly and require considerable skill and some expense to maintain properly. Because of this, many plants are inadequately equipped and lack proper equipment to obtain the best operation.

Pressure Gauges

Pressure gauges are normally supplied with the larger industrial compressors; one for high side, or condensing pressure, and one low side or suction pressure of the compressor. Pressure gauges will tend to get out of calibration after a few months of operation, particularly in the small sizes. The large pressure gauges (8 inches and larger) will usually keep their calibration for a considerable period of time. It is a good idea to check all gauges against a master gauge or other means at regular intervals. False pressure readings are worse than no readings at all. The standard pressure gauges are almost all of the bourbon tube type. The bourbon tube is a hollow tube, closed at one end and in the shape, more or less, of a question mark. A mechanical linkage is fastened from the closed end of the tube to a pointer. As pressure is admitted to the open end of the tube, it tends to straighten out the tube. This movement is translated to the pointer and calibrated on a round dial to read in pounds per square inch or other pressure indication. The tube is usually made of monel metal or stainless steel for ammonia and of brass or other nonferrous metal for the halocarbons, water, etc.

Pressure readings are important in analyzing the operation of a refrigeration plant. Condensing pressure, suction pressures of each header, where there is more than one low pressure header, should be taken at regular intervals. Water and other fluid pressures are important in and out of pumps as an aid to determining pump performance.

Thermometers

Liquid-in-glass type thermometers are probably the most frequently used in a refrigeration plant for determining various temperatures. This type of thermometer consists of a very small bore glass tube with an enlargement at one end. Mercury, alcohol and several other liquids are used as indicators. The liquid is sealed in the bulb. Changes in temperature cause the liquid to expand up the bore in the glass tube. This

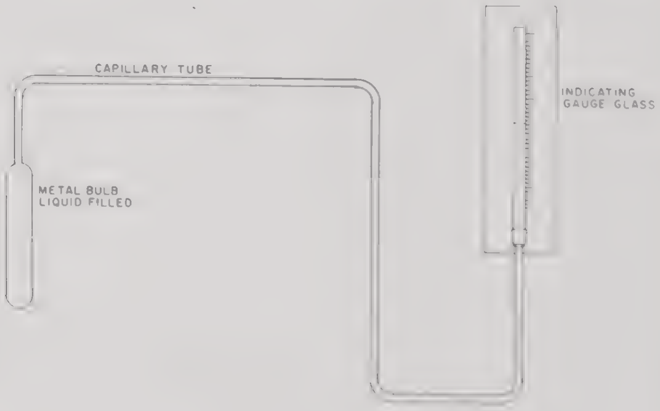


FIG. 13.1. REMOTE INDICATING THERMOMETER WITH INDICATING GAUGE GLASS.

expansion is observed and markings etched into the glass tube indicate the temperature being sensed. Glass thermometers are calibrated in whatever unit is required for temperature reading and are quite often fastened to a metal protective shield as a precaution against breakage. Sometimes the temperature scale is marked on the protective shield rather than etched in the glass itself. This can give an erroneous reading if the guard slips. Glass stem thermometers are accurate but are sometimes difficult to read, particularly in poor light. Magnification in the glass itself is used sometimes to enhance the readability. The limiting low temperature of a mercury filled thermometer is −40° F (−40°C) since mercury freezes at this temperature. Below this temperature, alcohol may be used.

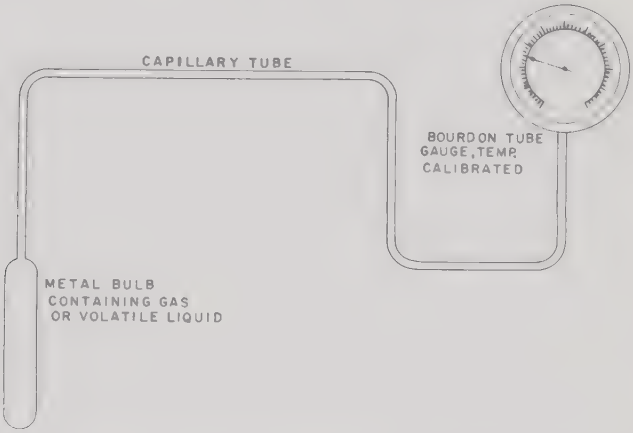

CAPILLARY TUBE
BOURDON TUBE GAUGE, TEMP. CALIBRATED
METAL BULB CONTAINING GAS OR VOLATILE LIQUID

FIG. 13.2. REMOTE INDICATING THERMOMETER WITH BOURDON GAUGE.

Temperature Measurement Precautions

Certain precautions are necessary for accuracy and safety when using glass stem thermometers. It should always be remembered that a glass thermometer is fragile and should be treated with care and rough handling avoided. The temperature imposed on the thermometer should not exceed the uppor or lower limit indicated by the range marked on the thermometer. When measuring temperatures far different from the room temperature in which the measurements are being made, the thermometer should be shielded to prevent room temperature influence. Care should be taken where thermometer wells are used that the thermometer is properly immersed in the liquid in the thermometer well to give an accurate reading and that the well itself is deep enough to be completely surrounded by the media being measured.

Other Temperature Measuring Instruments

There are a large number of temperature measuring devices on the market today. Some of these indicate temperature on some type of dial; others record temperatures at regular intervals on a suitable chart and still others are used to both measure and control. In cold storage operations, the glass stem thermometer is particularly useful in machine rooms and for spot testing in various areas. Table 13.1 indicates several types of temperature measuring instruments and their range and use.

Thermocouples

Thermocouples can be made up by using commercially available thermocouple wire and welding two dissimilar leads together to form a junction. These leads can be calibrated on a milivoltmeter equipped with a scale of temperature rather than milivolts. Thermocouples are useful for remote reading of temperatures such as the readings in various cold storage rooms from a central location. Such readings can be taken by an operator from a central location or can be arranged to operate a printer for permanent record taken at regular preset intervals. Almost any number of temperatures can be taken from a central location with the proper collecting instrument.

Bi-metal thermometers are made up with bi-metal strips that warp on a change in temperature. This warpage can be linked to a dial for reading temperature or to a switch to form a thermostat. Switches may be an open contact or mercury bulb but all serve the purpose of switching equipment on and off in accordance with temperature demands. By equipping the mechanism with a potentiometer, or sliding scale, a modulating control can be built which gives gradual modulating action instead of an on-off switching action. These modulating controls can be made to operate valve motors, modulating them to a partial open or closed position and also by proper cams and relays may be made to modulate machines on and off in a pre-arranged sequence.

Solid state temperature devices are also appearing on the market. These devices can be made to work with a very high degree of accuracy and with proper amplification can be used for control of refrigeration machinery. It can probably be assumed that the solid state control will continue to expand in its field of usefulness. Its present limitation is that very few operators understand it fully and hence have difficulty in reconciling to its functions in refrigeration control.

Liquid Level Gauges

Standard liquid level gauges usually consist of a glass tube open at both ends into the vessel whose liquid level is desired. The level in the glass

TABLE 13.1. TEMPERATURE MEASUREMENT

Instrument	Where Used	Accuracy Expected	Range °F	Range °C
Mercury thermometer	gas and liquid immersion	high	−38 to +375	−39 to +191
Alcohol thermometer	gas and liquid immersion	high	−100 to +100	−73 to +38
Pentane thermometer	gas and liquid immersion	high	−200 to +70	−129 to +21
Mercury with nitrogen gas	gas and liquid immersion	high	−38 to +1000	−39 to +538
Gas thermometer	standardization	very high	−459 to +1000	−272 to +538
Platinum-rhodium thermocouple	high temperature and for calibration	high	500 to 3000	260 to 1648
Iron-constantan thermocouple	general plant testing	fair	100 to 2200	38 to 1204
Copper-constantan thermocouple	general plant testing	fair	100 to 600	38 to 316
Chromel-alumel thermocouple	general plant testing	fair	100 to 2200	38 to 1204
Bi-metal thermometer	for rugged controls	limited	0 to 1000	−18 to 538
Optical pyrometer	for spot high temp radiation	1%	+4000	+2204
Seger cones	ceramic industry	3%	1000 to 3600	538 to 1982
Boiling and melting points pure materials	standardization	high precision	Established melting points of pure material	
Beckman thermometer	differential temperatures	high	10° differentials	5.5° Diff.
Tempil sticks	surface temperature	1%	125 to 900	52 to 482
Radiation pyrometer	high temperature radiation	5%	100-up	38-up

rises to the same level as the liquid inside the vessel thus indicating the amount of liquid present. Valves are installed so that in case of breakage of the glass, the vessel may be sealed off. On low side refrigerant vessels where pressures are low, the refrigerant temperature in the gauge glass may be below freezing and as a result, frost build up can obscure the reading of the gauge. Various heaters and other sealing methods have been used with varying degrees of success. One relatively good method consists of placing a float in a tube where the glass is normally placed. A gauge glass is then placed on top of this tube. A float with a rod attached is actually in contact with the refrigerant. The rod has an indicator on it and registers in a calibrated glass tube above the liquid level.

Glass bulls-eyes are also used by placing them in the side of the vessel being monitored. Various optical aids are used to ascertain whether liquid is present. Very thick lenses and heaters are used in low temperature to keep the glass free of frost.

Humidity Measurement and Control

For measuring humidity, the sling psychrometer can give rather accurate results. It is composed of a pair of thermometers, one of which is provided with a loosely knit fabric cover upon the bulb, which is wetted with water before use. Both thermometers are mounted in a frame equipped with a pivoted handle so that the thermometers may be moved rapidly through the air by revolving them around the handle. In air which is not saturated, the evaporation from the wet fabric causes the wet bulb thermometer to read a lower temperature than the thermometer with the dry bulb. The readings obtained from the two thermometers may be used to determine the relative humidity of the air measured. This is done with the aid of a psychrometric chart. The dew point may also be found when wet and dry bulb temperatures are known. This type of psychrometer can also be duplicated mechanically by mounting the wet and dry bulb thermometers on a stationary frame and using a blower to direct room air over them at velocities of 1000 fpm approximately. Another type of psychrometer utilizes the change in dimensions of fibers or membranes which absorb water from moist air. One type consists of a number of human hairs bundled together with one end fixed and the other attached to a pointer through a mechanism so that the stretching or shrinking of the human hair element will register on a scale calibrated in relative humidity. Other hygroscopic materials are also utilized. All of these instruments must be calibrated against a known instrument such as a sling psychrometer. They are not extremely accurate except over rather narrow ranges but serve to give an indication of the correct humidity reading.

A hygroscopic salt is sometimes used in connection with a resistance wire. The absorption of moisture by the salt changes the resistance of the wire path causing a difference in a minute current flow through the instrument and these changes in current flow are measured on a galvanometer calibrated to read humidity. This instrument is accurate enough for all practical purposes and has the advantage that it can be used at temperatures somewhat below freezing. It is also used as a control instrument as well as the others described. It is relatively expensive compared to either the sling psychrometer or hygroscopic element instrument.

Dew Point Hygrometers

Dew point hygrometers are available at prices ranging from a few dollars to several thousand dollars. They are very useful in some specialized storages where accurate control of dew point is desired, since they can be purchased as an indicating or control instrument or both. Dew point hygrometers give the dew point temperature in a single reading rather than requiring the use of wet and dry bulb thermometers and chart interpretation. The simplest dew point indicator utilizes a bright surface with a varying temperature. As the temperature is slowly lowered, condensation will begin to form when the dew point temperature is reached.

Fluid Flow Meters and Indicators

It is often desirable in a refrigeration plant to know the quantities of fluid flowing in a pipe and, in some instances, to know whether there is a flow or not. Flow meters and indicators are designed to give this type of indication.

Flow meters similar to the disc type used in water meters are used to measure the flow of refrigerants as well as other fluids. When used for this service, metals must be used in the construction of the meter that are not harmed by the refrigerant or fluid being measured. The parts must also be designed with sufficient strength to withstand the pressures imposed by the fluids being measured.

Orifice meters (Fig. 13.3) can be used satisfactorily to measure the flow of either liquid or gas. They are manufactured in types which indicate flow rate or which record flow over a period of time.

Figure 13.4 indicates a special vertical type of orifice meter which consists of a tapered transparent tube through which the fluid or gas flows upward against a formed plummet. As pressure forces the plummet upward, the orifice size is increased by virtue of the tapered cylinder. When a balance point is reached, the flow rate may be read on the

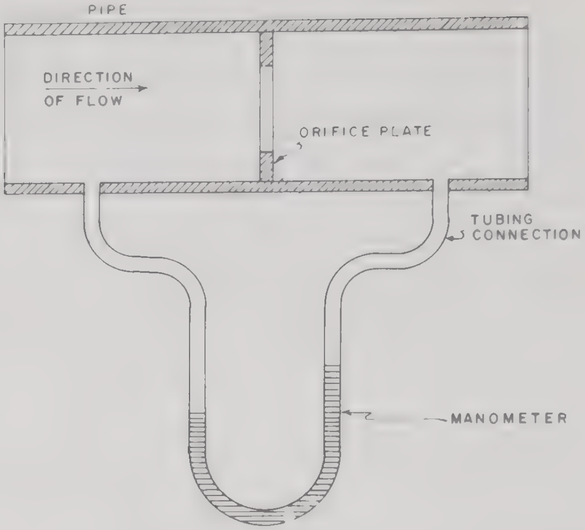


FIG. 13.3. SCHEMATIC DIAGRAM OF INDICATING ORIFICE METER

calibrated tapered tube. This type also serves as a flow indicator since the position of the plummet indicates there is a flow.

Flow indicators are handy aids in determining if there is a flow in a particular line. Various types are made for this indication, the simplest being a glass bulls-eye in the line where the liquid can be observed. To clarify the flow some type of stamped configuration is placed in the indicator opposite the sight lens. Liquid flow over this distorts the image making flow intelligence easily available. Other types use revolving wheels behind the sight glass or a pivoted vane which is raised by flow.

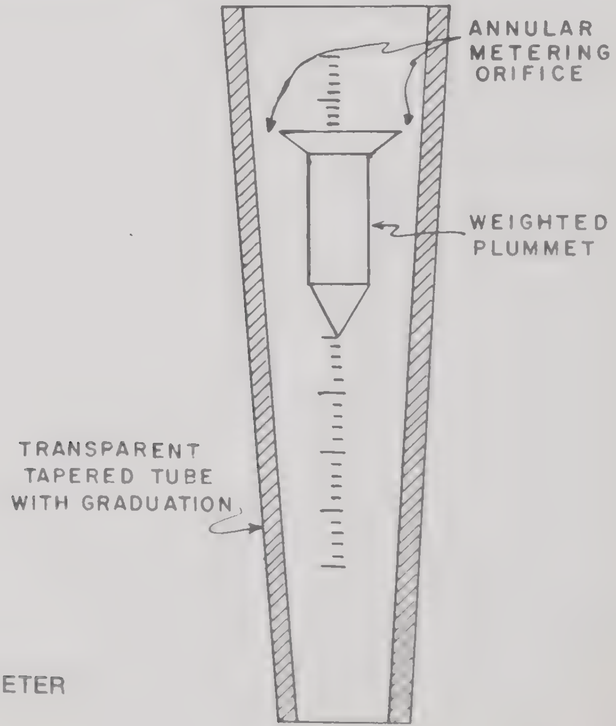


FIG. 13.4. VARIABLE ORIFICE METER

AUTOMATIC CONTROL COMPONENTS

Most controls in a refrigeration plant are used either directly or indirectly to regulate the flow of fluids. These fluids may be liquids, vapors or gases; hence, the majority of the controls are valves plus electrical switching devices for electrically actuated valves and also electrical switches for machine, pump and fan motor controls.

Generally there are two classes of controls in any area. One type is the two position control. It is either fully open or fully closed such as a simple thermostat which makes a circuit on a demand for cooling and breaks a circuit when the temperature is satisfied, the action being the same as that of a light switch. The second type is the modulating control in which a valve or device is modulated between open and closed and can assume any position between full open and closed. This control, in simple form, consists of a potentiometer type control such as a thermostat or pressure control with a pointer or hand that moves along an electrical potentiometer which is part of a bridge circuit. The other part of this circuit is mounted with an actuating motor on a valve or other device being controlled. A slight change in temperature will change the position of the potentiometer arm in the actuating device, which is compensated in the control motor so that slight changes produce slight movements and devices are thus able to modulate for a smoother more accurate control. Both types of control will often be found in refrigeration installations.

Liquid Levels Controls

Liquid level controls are used to control the depth of a refrigerant in a vessel to certain acceptable levels. Almost all ammonia systems will employ this device and in the larger halocarbon refrigerant systems, with liquid recirculation systems, they will also be found. There are two types most generally found in a refrigeration plant. The first type is the float valve. This is an enclosed valve mechanism operated by a float of stainless steel or other metal compatible with the refrigerant. The whole valve is enclosed to prevent leakage to the outside. As the liquid level falls in the vessel being monitored by the valve, the float drops and allows a flow of refrigerant into the vessel. As it fills, the valve begins to pinch off thus keeping a relatively constant level. The valve is also used in reverse action to keep a vessel such as a condenser drained of liquid but shutting off when the vessel is empty to prevent passage of gas. A float valve will operate well but is a regulating valve and after a time will not shut off completely allowing some leakage even when its monitored vessel is full. An auxiliary solenoid valve is quite often employed in conjunction with a float valve to insure tight shut off during off periods.

The second type probably used the most frequently is the float switch and solenoid valve combination. In this type of control, an enclosed float ball operates an electrical switch, usually by a magnet mechanism, so that the float is entirely enclosed in the refrigerant. A solenoid valve is installed in the liquid line feeding the accumulator or refrigerant vessel. As liquid is called for, the float switch makes contact to open the solenoid valve which feeds liquid to the vessel until the level is satisfied and the float switch breaks the circuit and allows the solenoid to close. The liquid is generally fed from the solenoid valve to the vessel through a hand control valve so that the rate of flow may be controlled. This is a very positive means of control in that solenoid valves are normally tight closing and over fill is prevented.

Temperature Controls

Temperature sensitive elements depend upon the change of dimensions which occur when a suitable material is heated or cooled. A strip made by welding together two layers of dissimilar metal has the property of warping with a change of temperature. By anchoring one end of the strip and attaching an electrical contact point to the free end and providing a second fixed contact, the warping of the strip will open or close a circuit with a change in temperature. This is the essential element of many thermostats. With the free end of the strip bearing on a potentiometer, a modulating control may be fabricated.

A glass thermometer with very fine contacts imbeded at intervals and with a mercury fill, may be used as a thermostat. As the mercury rises in the thermometer it makes contact with the wire and can complete a circuit. By amplifying this signal with a solid state device, a very accurate thermostat will result. A small bulb fitted with a tube connected to a bellows type mechanism may also be used as a thermostat. A volatile liquid or liquid and gas, or gas may be placed in the bulb. A change in temperature changes the pressure of the trapped fluid in the bulb, tube and bellows and changes the position of the bellows to operate a switching mechanism.

Pressure Controls

Pressure controls sense pressure changes in a refrigeration system and transform a mechanical action in the control to an electrical switching circuit. Pressure actuating mechanisms can be a bellows type moving with pressure changes or a bourbon tube type also moving with pressure change. Movement can actuate an on-off switching circuit or a modulating type circuit. In selecting pressure switches, the correct range of pressure should be chosen so that the desired operation falls somewhere in the middle of the operating range for best accuracy. The metal used in the pressure control should, of course, be compatible with the refrigerant with which it is working.

Flow Control

The expansion valve which meters the liquid refrigerant into the evaporator and actually separates the high and low sides of the refrigerant circuit is one of the most important controls in the refrigeration plant. In its simplest form, thic control is a hand operated valve of the needle type which is adjusted, by hand, to admit just enough refrigerant to the evaporator so that it is all evaporated by the time the evaporating liquid reaches the evaporator outlet. Because this type of control requires almost constant vigilance and frequent adjustment, it has largely been abandoned in favor of more sophisticated valves which operate automatically. These valves are called thermal expansion valves. They consist essentially of a valve body containing a needle valve and seat to meter the refrigerant. The valve is controlled by a diaphragm of some type open through a fine bore tube to a "feeler" bulb and this section filled with a volatile liquid. The force of the diaphragm is opposed by the system pressure plus an adjustable spring pressure and the balancing of these forces positions the valve to regulate the refrigerant feed. In systems with evaporators with moderate to high pressure drop in the refrigerant circuit, the pressure under the diaphragm of the expansion valve is taken from a point at the evaporator outlet and piped back to the valve. This is called an externally equalized valve and will give somewhat more accurate control than when pressure at the evaporator entrance is used.

The "feeler" bulb of a thermostatic expansion valve is mounted on the evaporator outlet (suction) line in a manner to assure good physical contact so that the bulb temperature closely follows the temperature of the suction vapor. When the temperature in the evaporator outlet exceeds a predetermined value, the pressure exerted by the volatile liquid in the "feeler" bulb moves the thermal valve diaphragm against the evaporator and spring pressure to open the valve and feed more liquid refrigerant to the evaporator. As more liquid is admitted to the evaporator, the temperature at the evaporator outlet decreases and the expansion valve feed is decreased in proportion to the temperature drop. By adjusting the spring tension in the valve, the valve may be set to maintain a constant superheat, or temperature difference between inlet or evaporating temperature and the temperature at the coil outlet. This prevents any flow of liquid back to the compressor and yet assures the evaporator has as much refrigerant admitted to it as it can safely use. Figure 13.5 illustrates an expansion valve and shows the various parts used to construct such a valve.

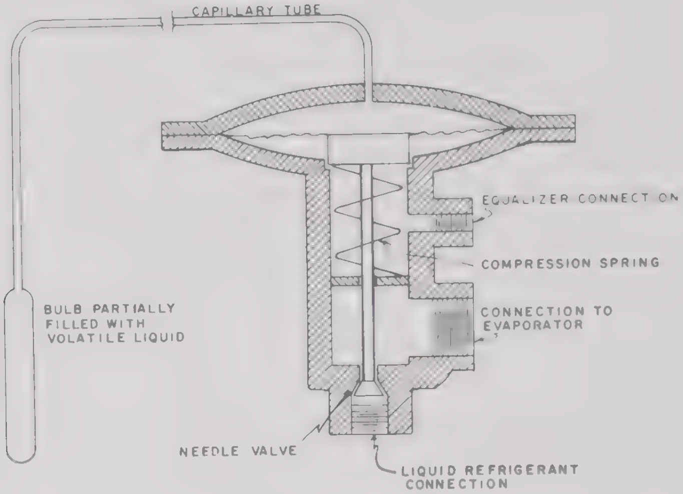


FIG. 13.5. THERMOSTATIC EXPANSION VALVE

The low side float control or float switch-solenoid valve is used with flooded evaporators and other vessels in which a liquid level control is desirable. Refrigerant is supplied only when vaporization is occurring. The metering effect of the valve allows any number of evaporators to be used in a system. The float valve is a valve operated by means of a float located either inside of an accumulator or in a float chamber which is connected in such a manner that the same level is maintained in the accumulator as in the float chamber.

High side float switches are used most commonly to drain vessels such as a receiver but to prevent passage of gas. In a critically charged system the receiver is usually run almost at the empty level. The high side float valve has an opposite linkage to the low side float and thus will stay open as long as there is a liquid level. When the liquid is drained to the point of control of the float, the valve shuts off. In this manner only liquid refrigerant flows to the evaporators.

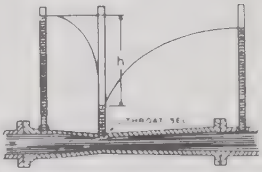
Capillary tubes

A capillary tube may be roughly defined as a small bore tube used either to carry a sensing pressure from one control component to another or used to reduce pressure of a refrigerant liquid from the high side pressure to the low side or evaporator pressure. The amount of flow is determined by the length and bore of capillary tubing used. Use of capillary tubes as expansion devices is limited pretty much to domestic refrigerators and small air conditioning systems. Since their length and bore is fixed for each application, their ideal control characteristics are met at only one point. On small systems they have the desirable characteristic of allowing system pressures to equalize during periods of shut down so that on start up, only the friction of the system parts offers resistance and relatively low starting torque motors can be used. Capillary tubes have very small bores and care must be used, when they are applied, to supply adequate filtering ahead of them since small particles can clog them and render them ineffective. This type of feed is mentioned only in passing interest. It would be a rare thing to find this device in the operation of a cold storage warehouse.

MISCELLANEOUS CONTROLS

There are a great many controls available for refrigeration plants. Most of them will be found to be some variation of a pressure, temperature, flow or possibly humidity control. Almost all types of controls can be built as off-on contact switches or can be built as modulating controls depending on the purpose for which they are intended or the sophistication of the control system with which they are used.

Flow nozzles, or flow meters are sometimes used in warehouse operations where it is felt desirable to obtain the amount of flow of a liquid.



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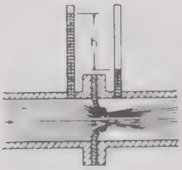
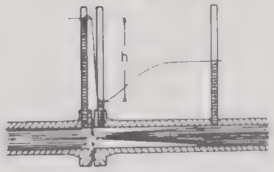


FLOW NOZZLE



ORIFICE PLATE

FIG. 13.6. THREE TYPES OF PRIMARY ELEMENTS USED TO OBTAIN DIFFERENTIAL PRESSURE MEASUREMENTS.

In lease agreements for refrigertated space, charges for energy used in refrigeration can sometimes be predicated on the amount of refrigerant flow to the leased area. The same may also be used for measurement of brine flow. There are several methods of obtaining fluid flow numbers.

TABLE 13.2. MEASUREMENT OF DIFFERENTIAL PRESSURES

Instrument	Where Used	Range	Accuracy to Anticipate % Error
Manometer	low and medium differential pressures	0 to 100 in. Hg	within ½
Bourdon coils	low pressure and high pressure	0 to 2000	within ½
Draft gages	low pressure	0 to 10 in. H_2O	within ½
Bellows differential pressure units	low to very high pressures	0 to 3000	within ½

Differential pressure switches are used quite extensively as safety control on compressors by sensing the pressure difference between lubricating oil pressure and crankcase pressure. These switches can be set to actuate the control to shut down the compressor in case the difference between oil pressure and crankcase pressure becomes so low that flow cannot be maintained. A time delay is usually incorporated in these switches to overcome nuisance trippings during start up when differential pressures may be low for short periods.

Pressure regulating control valves are used quite extensively in some specialized application. The pressure control regulator will operate to maintain a set pressure in a refrigeration evaporator regardless of the suction line pressure; so long as the suction pressure is equal to or lower than the desired evaporator pressure. A reverse type of regulator is sometimes used as a crankcase regulator with a refrigeration compressor. When used in this mode, the valve will not allow refrigerant gas flow to the compressor at over a preset pressure. This is useful on start up of some systems where the compressor might be overloaded by high suction pressures during the starting period of the system. The hold back valve will prevent this excess pressure during this period and then gradually open as pressures settle back to design conditions where the compressor is not overloaded.

Pressure regulating valves can be modified in many ways to produce a variety of results. By the addition of a small solenoid valve, they may be made to act as stop valves. Also two different suction pressures may be controlled by one pressure regulator with two pilot regulators so that control can be shifted from one pressure to another by the same valve. Regulators can also be modulated either electrically or pneumatically by thermostat to hold high humidities in a room by keeping the evaporator temperature as high as possible consistent with the desired temperature.

Many valve and combinations of valves are used in cold storage operations and all of them perform some useful function. However, in a good design, control valves should never be used in quantities in excess of that needed to do a job. Do not install control valves controlling control valves. Systems should be entirely adequate for the purpose intended; but avoid Christmas trees.

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14

Refrigeration Control Systems

Probably every refrigeration plant has some type of control to aid in the operation of the system. These may range from a very simple system used with a small plant to a complicated and sophisticated system used in a large cold storage warehouse complex. In a large plant, the control system can often represent a substantial percentage of the cost of the entire plant.

FULL AUTOMATION

There are simply not enough trained operators to operate a large complex refrigeration system by hand on a 24-hour basis. At the present writing, it does not appear that this will happen in the foreseeable future. Because of this, owners of refrigeration using industries have been forced into automation of their facilities. This is not a bad thing, since with proper application of controls and other automatic components, very efficient and smooth operation can be achieved without the continuous attendance of highly trained operators. While automation of a plant means that the operation of the plant is largely, or wholly, automatic, it does not mean that a large plant can run unattended. Routine maintenance will always be required and the chief engineer or chief operating engineer must be a person who is well trained in the operation of their particular plant. Any mechanical part can fail and control systems can also have failures. Someone in the plant needs to have a thorough working knowledge of the plant, its controls and its complete operation. Automation frees personnel for more important duties than operation and will require less personnel but will not eliminate the necessity of some topflight people if the plant is to be operated successfully.

With automated control, a plant may be constructed that will operate reliably and efficiently with one daytime shift of topflight operators, if regulations permit. The automation will free personnel for routine maintenance and overhaul, housekeeping and other duties vital to good operation. The chief engineer of the plant should be thoroughly familiar with the design and also with the operation of the plant as envisioned by the designer since he will be the one to set and adjust the controls to achieve the desired conditions. A mal-adjusted plant or a plant whose intended functions are misunderstood can give unlimited trouble. Personnel required will depend on the size and complexity of the plant as well as the amount of maintenance, repair and other duties not necessarily relating to the refrigeration plant that are required by the management.

There are savings in plant automation other than in fewer personnel. Since an automated plant is under constant surveillance of its controls, it can, with proper settings of controls, be made to run at high efficiency at all times. This is extremely desirable with increasing power costs and scarcities of energy.

The small refrigeration plant usually serving one or two relatively small areas is normally unattended, the controls handling the operation and there being not much maintenance required daily of such a plant. Regular inspection and maintenance should be scheduled with a service organization or individual so that signs of trouble may be detected before actual damage or shut down occurs.

Solid State Controls

Solid state controls are coming into rather wide use at the present time as well as a constant stream of other types of new controls. It would seem to be a reasonable assumption that at some future time, most controls will use solid state circuitry in some form or other. Functionally controls will probably remain the same regardless of the type used as long as the present concepts of refrigeration are used. One of the present drawbacks to solid state and other unitized controls is lack of personnel who understand them and can service and adjust them for proper operation. Solid state designers sometimes talk an entirely different language from the cold storage plant designer and interchange of ideas is difficult. Regardless of the type control used, certain functions are required and certain results are desired. Any discussion of the ideal control situation in any refrigeration plant is basically a description of the actions desired of a control system and are valid regardless of the type of control used so long as it performs its desired duty. It is also necessary that all of the control components of a given plant work together in complete harmony to produce an efficient operable plant.

THE COMPLETE CONTROL SYSTEM

An ideal control system serves a number of functions, all integrated into one complete interdependent system. The small system usually requires an extremely simple control system while the control for a large warehouse may be very complex. The automated control system for any plant, regardless of size should operate the complete refrigeration plant without any manual assistance by operating personnel. It should maintain selected temperatures in the various cold rooms of the facility so that the entire operation of the refrigeration plant is automated and will perform its several functions without human assistance. As stated before, automated plants can operate independently but, in larger plants, automated does not mean unattended.

A complete automatic control system actually contains several subcontrols. Some of these functions are overlapping but broadly speaking may be divided by their function into (1) prime safety controls, (2) component safety controls, (3) machine room operating controls, (4) remote room temperature controls, and (5) malfunction indicators. The last category is not strictly a control but is an integral part of the complete system when used.

Prime Safety Controls

In the completely automated plant, a number of safety controls are usually installed that can be termed "prime safety controls." These controls are designed to shut down the entire plant in case of failure of certain components that could jeopardize the machinery or safety of personnel in the plant. Examples of prime safety controls are high compressor discharge pressure cutouts, brine pressure failure switches, low brine temperature cutouts, low pressure refrigerant cutouts (other than operating control), high liquid level cutouts for accumulators and other cutouts that will act in case a situation develops that may cause harm to the plant in general. For safe operation, these controls should normally be of the manual reset type so that the plant will not start itself up until the situation causing the prime safety to act has been corrected. If the plant is without attendants during certain periods, then the prime safety controls can be wired to actuate a signal or telephone so that this can be picked up by a watch service and relayed to a designated individual employee. After a prime failure, it is good practice to restart the plant manually after correcting the cause of the failure to be sure that everything is in proper working order. In a well maintained automatic plant, it will be found that failures in the prime safety controls are rare and call backs to the plant for this reason do not occur except at rare intervals.

Component Safety Controls

This set of safety controls is also important to the automated plant. They are installed to protect the various individual units in the plant. They do not shut down the entire plant as do the prime safeties, but only an individual compressor or other component of the plant they are installed to protect. These controls may be individual machine high pressure or low pressure controls (other than low pressure operating control), cylinder high temperature cutouts, bearing temperature cutouts, oil pressure failure switches and other protective controls. Vibration controls are sometimes used to stop machinery in case of excessive vibration. These individual safety controls can be designed to lock out a particular component until reset by hand or to automatically reset as required in the overall design of the particular control system involved.

Machine Room Operating Controls

The machine room operating controls govern the operation of the refrigeration equipment in the machine room, or sub machine room when used. Generally, it will be found that the refrigerating machines will operate primarily from pressure controls and not directly from the temperatures maintained in the various rooms. By operating in this manner, the refrigeration plant will maintain certain set system pressures throughout the plant independently of the number of rooms calling for refrigeration. Sophistication of controls allows for unloading and loading of individual compressors as well as complete stopping and starting of compressors as required by the plant operation. This all makes for a very flexible method of control that is relatively simple in operation and will function with a minimum of difficulties.

Remote Room Temperature Controls

Room temperatures are maintained normally through the use of thermostats located in the cooled areas. In direct expansion coils cooling rooms, the thermostat normally will open or close a solenoid valve in the liquid line supplying liquid refrigerant to the unit expansion valve which effectively regulates the temperature of the room. In brine cooler rooms, a motorized valve is controlled from a thermostat. The use of a motorized valve is for slow opening and closing to prevent shock and hammer in the brine lines. Cold rooms with liquid recirculation units also normally use a solenoid valve operated from a thermostat for temperature control. Defrost control stations may also be set up at various room locations to control the defrost cycle and return the defrosted coil to normal service.

Malfunction Indicators

While not strictly a control, the malfunction indicator can perform a very useful service in the automated plant by indicating the source of a shut down. These systems can be as simple or as elaborate as desired. They normally consist of a special panel containing a number of lights which are connected to various safety switches so that when a failure occurs and the switch opens, it also completes a circuit to light an individual light. This light can be behind a printed opaque cover indicating the control functioning or can be designated in some other way. As a further refinement, the prime safeties, and other if desired, can be circuited to a telephone line and relayed to a watch service or operator during times that the plant is unattended.

FLICKER CONTROLS

Many control systems will shut down completely in case of a power failure. Those with automatic restart will restart the plant when power is restored. In some areas where a plant may be located somewhat remotely from its power source and where electrical storms are common, nuisance trips may occur from flickers in the power supply lasting only three or four electrical cycles but still sufficient to de-energize the control system holding coils. Even with automatic restart, each shut down can lose a certain amount of refrigeration time and numerous restarts are not desirable. To combat this type of very short duration power outages a relay may be used that will maintain contact for a matter of a fraction of a second before dropping out so that outages from very short duration flickers will not shut down the plant but allow it to continue on. The relay should have a retention time of less than required for any of the motors in the plant to slow down appreciably. Since power line flickers are normally reset automatically in a time of only miliseconds, they work well with this type of outage.

SEQUENTIAL CONTROLS

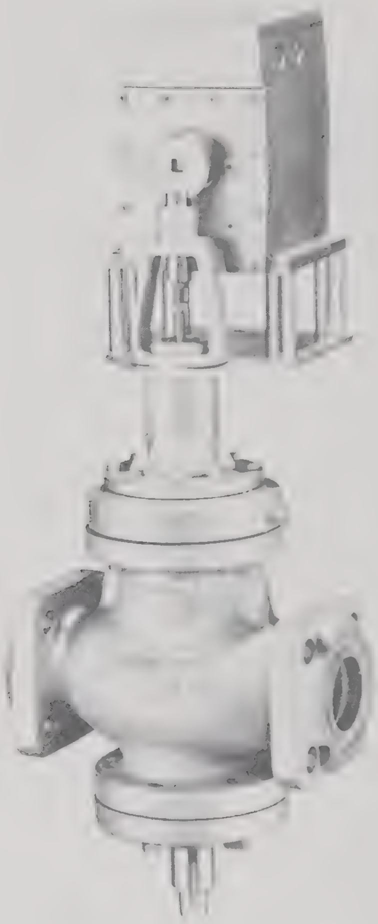
Sequencing controls can be very useful for the control of compressors in the machine room. This type of control is normally actuated by plant suction pressures. As pressure of the particular suction being monitored rises beyond the set limits, the pressure control acts to start an additional compressor or, if capacity controls are used on compressors, to add to the capacity of the monitored suction by the automatic manipulation of the capacity controls plus the starting of additional compressors when required. The controller will usually take the form of a modulating control motor with various control switches or cam and switches mounted to the shaft, the motor rotating a few degrees at a time to add capacity as the shaft rotates in one direction or to subtract capacity as it rotates in the opposite direction. The directing pressure controller is normally of the standard potentiometer type with standard electrical bridge balancing circuit which governs the movement of the controller motor to meet the varying capacity needs of the monitored suction pressure. In large plants with a multiplicity capacity steps, two or more such devices may be required to cover the number of capacity steps available. An end switch on the first control motor actuates the second controller, etc.

A forcing relay is sometimes employed as a further refinement to this type control. When a plant is shut down due to power failure or any cause, the forcing relay will force the controllers back to a zero position and then start the plant in a sequence as set on the controller after power is restored. This prevents a start up of a complete plant at one time and brings the plant on stream gradually without shock and without high taxing demands on the machinery.

Water pumps, condenser fans and other related equipment can be started up from relays controlled by compressor operation so that complete operation of a plant can be monitored from the sequence controller with added relays and starters all integrated into a smoothly operating control system that will control a plant from a position of minimum load to maximum load without encountering a condition of strain or overload. Most larger plants will require more than one suction pressure. Separate sequencing controls can be used to monitor each suction and the compressors involved both for high stage pressures or low stage booster suction pressures. In two stage compression systems with booster compressors, it is usual for the control to hold the boosters out of operation unless the high, or intermediate stage machines are operating or brought on the line. This prevents booster compressors from cycling in and out on safety controls with possible damage.

TEMPERATURE CONTROLS

Room temperature controllers are located in the rooms being cooled as well as humidity and defrost controls as required. Above 35° F (2° C) defrost is usually accomplished by shutting off the refrigeration to the coil being defrosted for a specified time by means of a time clock and letting the heat in the circulating air melt the frost from the coil. Temperature in the room is normally controlled by a thermostat operating a solenoid valve which controls the flow of refrigerant to the coil. This type of temperature control is quite commonly used for both coolers and



Courtesy of Refrigerating Specialties Co.

FIG. 14.1. ELECTRICALLY MODULATED BACK PRESSURE REGULATING VALVE.

Electric damper motor operates cam in response to thermostat to regulate refrigerant pressure in evaporator to maintain desired cold room temperature.

freezers. It can control room temperatures within reasonably close limits. Defrost controls in freezers are somewhat more elaborate since a positive means of defrost must be employed.

A very fine method of temperature control for any type of evaporator coil is the modulating back pressure regulator. This type of valve modulates the suction pressure, and hence refrigerant temperature, in response to the temperature requirements of the room. The back pressure regulating valve is actuated by a modulating electric or pneumatic type motor similar to those used in the operation of automatic dampers, the motor shaft being linked to the adjusting mechanism of the back pressure regulator. The modulating control motor is, in turn, actuated from a room thermostat set at the desired room temperature. The suction pressure is thus modulated to maintain a constant room temperature. This method of control allows the complete use of all of the evaporator surface in the room at the highest refrigerant temperature consistent with holding a constant room temperature. By the maintenance of the highest coil temperature, the highest possible humidity condition will be maintained in the room. By adding a solenoid valve to the back pressure mechanism, complete shut off of the valve may be obtained for defrosting. When this is done, a relief regulating valve should always be used to prevent excessive build up of pressure in the evaporator coil.

Manually set pressure regulators can also be used to good advantage where different suction pressures are required in different rooms and where the loads imposed by the rooms are not great enough to require an additional compressor and suction line. Almost any pressure can be maintained by a back pressure regulator higher than the plant suction into which it feeds.

BRINE TEMPERATURE CONTROLLERS

In plants employing brine circulation for cooling, the brine temperature is controlled to preset limits at the chillers. Modulating back pressure regulator valves, as described previously, also work well on brine chillers to maintain constant brine temperatures. As the brine flows to the various cooling coils in the cold rooms, it must be controlled to hold proper temperatures in the rooms. It is not desirable to stop brine flow for control, therefore, some type of bypass control is usually desirable. An automatic three way valve is often used, temperature controlled, to permit brine to flow through the cooling unit, or bypass around it to maintain proper room temperature. In some instances where a small special temperature room is required demanding a brine temperature higher than the existing brine system temperature, a brine blending system may be used. This requires an auxiliary pump at the room being cooled. The pump recirculates a portion of the brine through the cooling coil. By proper proportioning of the brine from the chiller and recirculated brine, almost any brine temperature above the plant brine temperature may be maintained. This method of brine temperature control is useful for small remote coolers or other special temperature requirements for a warmer brine than available in the plant.

TEMPERATURE AND DEFROST CONTROL

Any rooms operating at temperatures below 35° F (2° C) should have some means of defrost other than room air blowing over the coil. These methods are discussed in another chapter. Adequate controls to operate the defrost cycle need to be provided so that defrost may be accomplished automatically. These controls are usually set for time clock operation so that defrost is accomplished at certain preset intervals. Electric time clock controls are normally employed that both initiate the defrost and program cycle as well as place the coil back into the refrigeration mode. Various relays, contactors and other related devices are used in conjunction with the timer as required.

As refrigeration plants increase in size, the control system usually becomes more complex since the number of functions and machines to control increase as size of plant increases. Care should be exercised in the design of a control system that controls are not installed that simply control controls. In other words, always make sure that a control system is as simple as is consistent with the functions desired, using adequate controls to insure complete safety, reliability and operating efficiency, but avoiding the use of controls that serve no real useful purpose and only complicate the system.

CONTROL PANELS

Control systems are sometimes placed in rather elaborate housings and equipped with a myriad of indicating lights, gauges, alarms and other accessories. An elaborate system can run into considerable expense in a large plant but in addition to giving centralized information on the plant operation, it can serve a distinct advertising purpose and the publicity value of a good indicating system should be given some weight in making decisions on the control center. The appearance of a neat, well kept machine room with a complete indicating and operating panel is impressive to visitors and prospective customers.

In automated plants where the operating crew is kept to a minimum, the addition of a trouble indicating panel can have distinct advantages. Panel alarm systems are obtainable commercially and are usually composed of a main square or oblong panel divided into a number of small spaces. Each small space has an opaque cover on which is lettered the function it monitors, such as oil failure, high temperature, etc., and also the particular machine or equipment referred to. An indicating light is installed in each small space to light if a failure occurs in the equipment being monitored. Each safety switch in the plant may, if desired, have a corresponding space on the alarm panel and by proper wiring, when a safety is tripped, a light may be made to operate behind the space indicating the failure. An operator, or maintenance man can tell by a glance at the panel, just where any trouble may be. These panels can be as elaborate as desired and contain from a very few to a hundred or more alarm and failure notations. A further step may be taken by connecting the alarm panel to a call system where a failure occurring during times when the plant is unattended will send an alarm to a watch system or plant personnel by telephone line. Normally, only prime safety controls

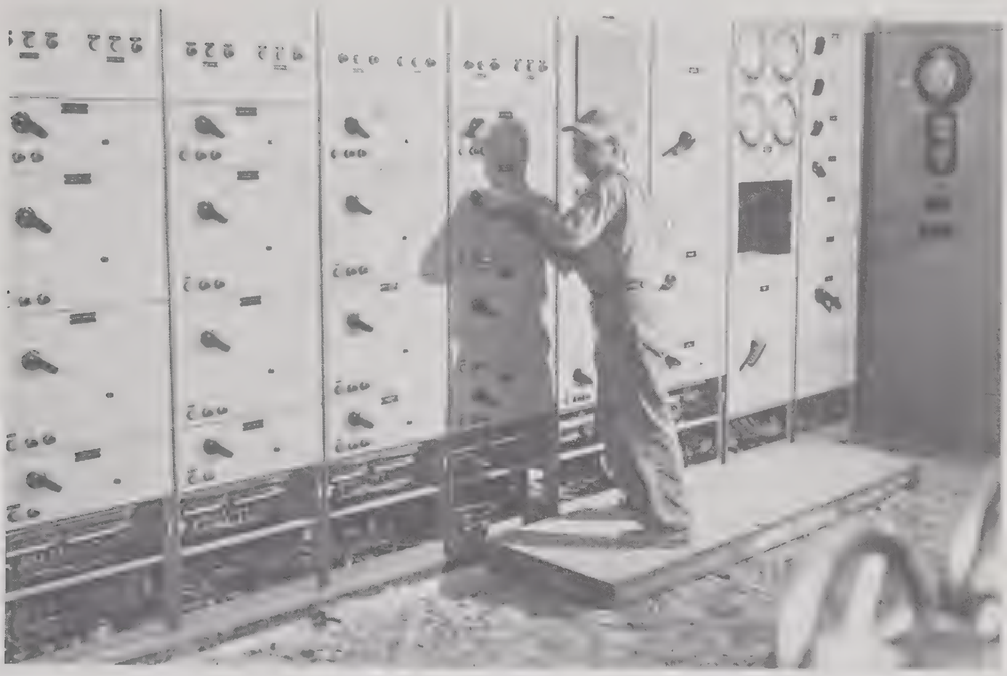


FIG. 14.2. CONSTRUCTION PHOTO SHOWING LOAD CENTER AND SWITCHING CONTROL PANELS FOR INTERMEDIATE COLD STORAGE FACILITY

Note indicating lights at various switching controls. Small panel above operator is an alarm panel. Each small square indicates a malfunction, when lighted. Complete plant automation controlled from this center.

are hooked to the watch service. During occupancy periods the outside line may be switched to an audible horn or other signal within the plant.

Operating lights are also useful placed at various equipment starters and for other indications of the components operating about the plant.

Temperature indicating instruments are a good investment in any cold storage plant. These instruments can be of the automatic printing variety which indicate a multiplicity of temperatures throughout the entire plant at regular intervals. Charts made on such an instrument should show the date and time and should be filed in a safe place. They can be valuable if a question is raised as to storage temperatures in a plant location.

Good housekeeping is essential in any well run plant. A good layout with good instrumentation and operating center that is kept clean and attractive breeds good housekeeping in the rest of the plant.

CONTROL CENTERS

Most modern plants concentrate all electrical control and starting equipment in a load center type enclosure, or multiple enclosures, located in or adjacent to the machine room. The panels in the enclosure contain the various starters, relays, transformers, switches and other electrical gear for the entire plant. With this type of distribution, most designers will combine the various operating lights, alarm systems, reset switches and other control items into the control center. In some instances, a flow diagram may be installed to show the principal refrigerant circuits and machines in the plant along with indicating lights which are illuminated to show machinery, valves, dampers, etc., in operation.

SWITCHING CONTROLS

In large plants where loads can vary from time to time, it is quite often an advantage to be able to switch various refrigerant compressors from one suction pressure to another. This switching can be accomplished by push button if desired, the push buttons operating various solenoid valves to accomplish the switching. Automatic switching, however, is only used at infrequent intervals in the normal plant operation and it is recommended that switching of compressors be done manually instead of by push button since the expense of automation in this area can seldom be justified. When a machine is switched from one suction, or condition, to another, it should be locked into the control system affecting its new operation.

CONTROL VARIATIONS

Variations of automatic control are endless depending on what the designer and owner desire and the completeness of automation needed. A good design will function correctly and with minimum trouble over long periods of time. With controls set properly for best operation, a plant may be operated at peak efficiency within its capabilities at all times. This is important in this period of high power costs and energy shortages. It should be again stressed that an automated plant does not mean an unattended plant, particularly in larger installations. Such a plant will operate for periods without attention but there should always be one or more top operating engineers employed as regular personnel of the plant who thoroughly understand the control system and its objectives and who can keep the controls in proper adjustment. Controls only function when they are connected properly.

FUTURE CONTROL SYSTEMS

Solid state controls and sensors will undoubtedly play a more important part in plant automation in the future than they have in the past. Functionally, they will do the same things as the controls most operators are familiar with. Computer analysis and aid in operation will surely be a factor in future control systems and is even now seeing some use. If and when these controls as well as other controls not yet developed are in use, it should behoove the owner and designer to be sure that such controls do the job required and are not too elaborate for the job at hand. Also that the operating or chief engineer in the plant understands the controls, their setting and repair so that a failure cannot cause a lengthy shut down until someone knowledgeable in their operation is found to diagnose the problem. As in present control systems, the design of the future should not over control, but rather perform the essential functions required for operation, safety and peak operating efficiency.

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15

Defrost Methods for Cooler and Freezer Coils

Any cold storage room where the refrigerant temperature is below freezing will normally require some type of periodic defrosting. This will usually include any room held at a temperature of 35°F (2° C) or below. When refrigerant temperatures are appreciably below freezing, ice and frost will form on the air side of the evaporator. This accumulation will grow in thickness with the passage of time and, in finned coils, may completely block the passage of air by filling in between fins so that no further cooling can take place. A positive method of removing the accumulated ice and frost is needed therefore, that will accomplish the removal in a reasonably short time so that the coil may be placed back in operation before room temperatures are adversely affected. Strangely enough, defrosting is sometimes more difficult in rooms held near the freezing point than colder freezer rooms. This is caused by the fact that at near freezing, ice rather than frost tends to form and the ice is harder to remove than the lighter frost formation at freezer temperatures. In some installations of blast freezing at very low temperature, defrosting is seldom necessary as the frost, in hard crystalline form, is blown from the coil as it forms. A blast room however, needs to be swept out at intervals as the accumulated frost will deposit around the room.

BASIC DEFROST SYSTEMS

There are six basic types of defrost systems that are used most frequently in the modern cold storage plant. These systems are (1) air defrost, (2) water defrost, (3) electric defrost, (4) hot gas defrost, (5) continuous liquid defrost, and (6) hot brine defrost. All of these systems may be found in one form or another in cold storage plants operating today. There are advantages and disadvantages in each system. All of them will work and give satisfactory results if designed and installed properly.

Air Defrost

The air defrost system is the simplest form of defrost that can be used. Since air defrost, in simple form, relies on a source of room air above the freezing point, it is obvious that it must be used in cooler installations maintaining a room temperature above freezing. A cooler temperature of 35° F (2° C) or above will normally provide warm enough air to defrost. The defrost operation is simple. The refrigeration to the coil being defrosted is shut off and the unit fans allowed to continue in operation. The above freezing room air flows over the coil surface, melting the ice and frost which drips into the drain pan and is removed from the room. This type of defrost utilizes only three or four degrees change in air temperature and is relatively slow compared to other systems but is entirely satisfactory, particularly in small and intermediate installations. It is not usually effective in room temperatures below 35° F (2° C) unless the room is allowed to warm to this temperature to accomplish the defrost. In view of the relatively long defrost periods, coils need to be oversized to compensate for the length of the daily defrost periods.

In rooms where some type of humidity control is required, air defrost can be a hindrance since humidity is removed from the air by the coil in the ice and frost. During defrost the ice and frost turn to water and since the fans are operating, a certain portion of this water will be evaporated tending to raise the humidity in the room. This can cause problems if close humidity control is desired.

Controls for air defrost are simple. They consist of a solenoid valve or other means of shutting off the refrigeration to a coil for a specified time and then allowing refrigeration to continue as required. A time clock can be installed to make the defrost completely automatic. Brine fed cooling units can also utilize this system of defrost by shutting off the flow of brine to the coil by means of a motorized shut off or bypass valve.

Forced Air Defrosting

A second type of air defrost that is sometimes employed in below freezing rooms such as holding freezers and other freezer applications is the forced outside air system. In this type of defrost, the cooling coil and fan are contained within an insulated enclosure with two sets of doors or dampers. During refrigeration, air from the refrigerated space is circulated over the coil and is cooled as in any standard cooling coil, the cold air being returned to the cold room by the unit fan. To defrost, the refrigeration is stopped in the coil and the coil closed off from the cold room. Outside doors are then opened into the coil compartment and warm outside air blown across the coil to defrost it. In cold climates, during winter operation, some provision for heating the defrost air must be made. In this type of defrost there is very little moisture regain in the cold room since the cooling coil can be isolated from the cold room until it has completely drained. The coil itself can also be chilled to operating temperature before being returned to room service.

Water Defrost

Water defrosting of coils came into vogue several years ago when it was discovered that water could be introduced into a freezer room to flow over an iced coil and that the water would melt the ice and frost and all flow out of the room without freeze up of the water. The secret of water defrost is to move the water in considerable volume and velocity so that it does not remain in the freezer area long enough to freeze. The coil being defrosted needs sufficient volume of water to remove the ice and frost rapidly. Installations have operated successfully where defrost water is pumped as far as 100 ft (30 m) in an uninsulated line through a freezer to the coil and drained back a like distance without freeze up. Water lines should be pitched to drain outside the cold room through proper traps placed outside the room to prevent any back feed of outside air through the drain lines when they are not in use. Cooling coils may be flooded with water by sprays or by perforated pans depending on the design. Regardless of the design, a plentiful supply of water should be used to assure full flooding over the surface of the coils. Any water source may be used, preferably a source over 50° F (10° C). Treated water from cooling towers or any water containing contaminents that might be harmful to food products should be avoided.

Water defrost can be accomplished automatically by the use of proper solenoid refrigerant and water valves and other controls and safeties. Control is obtained through a time clock. Piping water over a large plant can prove expensive as well as a disposal system either returning water to a central point or the disposing of it to waste. For this reason, it is probably not often used in recent plants since more compact and less expensive systems have been developed since the advent of the water defrost system.

Blast freezer coils and some larger coil installations do employ water defrost in some new installations. Water defrost provides a fast and complete defrost and is easily adapted to larger single units. Some other specialized freezer applications may also use water defrost, either alone or in conjunction with hot gas. Water defrost is probably best operated manually rather than automatically. Safety devices for automatic water defrost operate well but even an occasional failure can pile goodly amounts of water on the floor which immediately becomes a mound of ice in a freezer. Manual or semi-automatic operation with an attendant present during defrost presents a minimum possibility of trouble and can be used with great success in applications requiring a rapid thorough defrost.

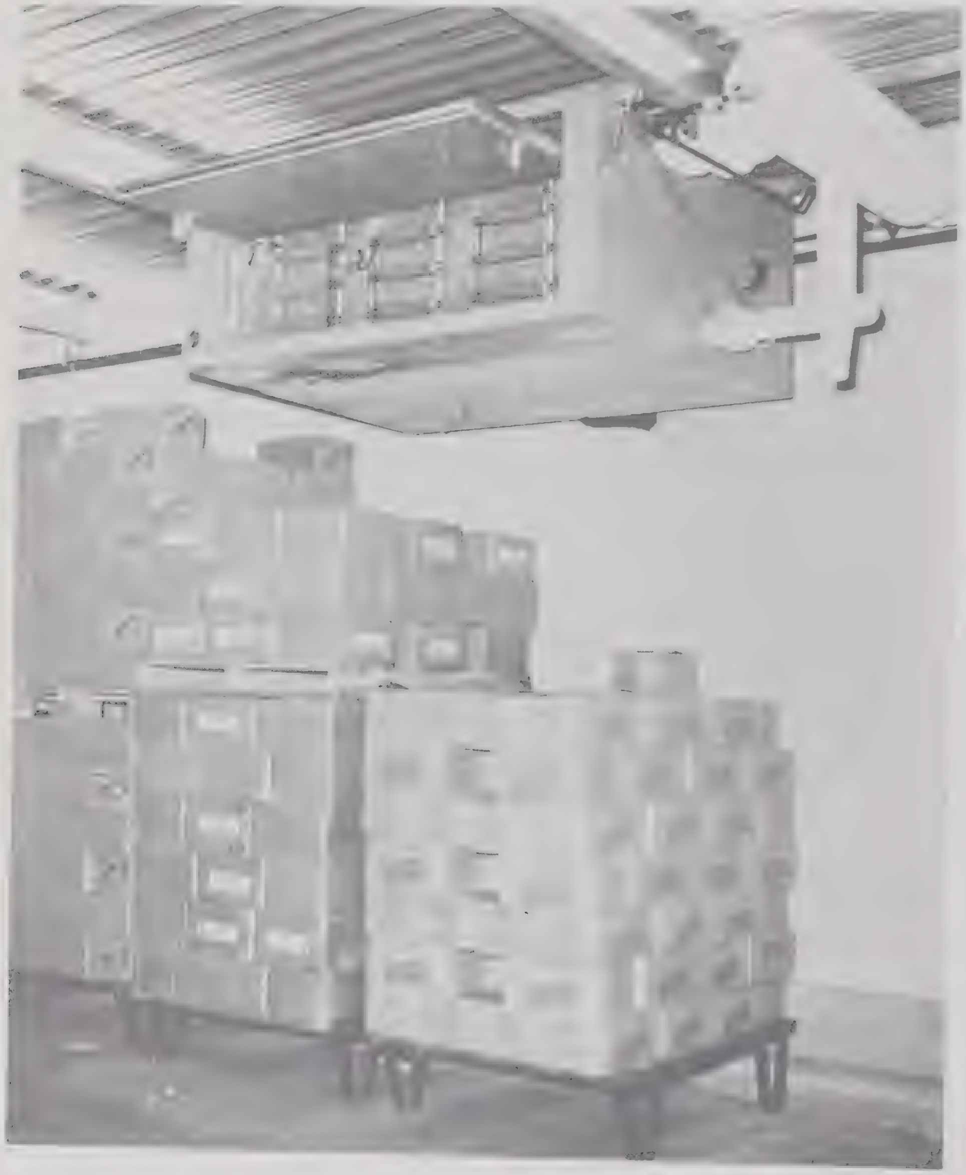
Electric Defrost

Electric defrost systems are quite popular since they are simple to install and operate and give good results as far as defrosting is concerned. In the usual system, refrigeration is cut off to the coil, the blower fans are stopped and heat is applied to the coil by electric heaters. In some instances, the heaters may be external to the cooling coils and operate by convection, heating the air that surrounds the coil which, in turn, melts the ice. In other configurations, electric heater rods are run through some of the tubes of the cooling coil thus furnishing a more intimate contact between coil and heater for a faster defrost. Electric defrost is very useful, particularly for isolated coils located at some distance from the machine room.

Electric defrosting requires a considerable amount of electrical energy and where used extensively, can involve additional electrical demands on a plant and also extra wiring to the various cold rooms. When used extensively, care should be taken to see that wiring is adequate and electrical capacity required is available at the various points of application. It is also well to check the amount of power required from a cost standpoint and also consider possible future costs with rising energy prices.

The simplest type of electric defrost coil consists of heater elements placed immediately below the coil. For defrost, the refrigeration and unit fans are stopped and current applied to the heater elements. The electrical elements heat the air surrounding them and the warmed air rises over the coil defrosting it. Heater elements are placed in a variety of positions in and around the cooling coil by different manufacturers in an effort to achieve even and rapid defrost. Upon completion of the defrost period and after a drain period, refrigeration is resumed by the coil.

Some electric defrost coils have been equipped with a light weight shutter, or louvre, which is held open during cooling by the pressure of the air fom the unit fan. When the fan is stopped for defrost the door closes by gravity thus enclosing the coil in a more or less tight box which tends to hold the heat in the coil to a greater extend than an open coil. This helps to accomplish defrost in a rapid manner and serves to return the coils to refrigeration in less time than with the open coil. Since the defrost is more rapid than with an open coil, some current is saved in defrost over a conventional coil. The pressure created by the fan on resumption of refrigeration blows the coil door, or louvre, open so air can again circulate within the cold room.



Courtesy of Krack Corp.

FIG. 15.1. ELECTRIC DEFROST COOLING UNIT

During defrost, door is closed and interior air circulated over electric heaters and coil for defrosting.

A third type of electric defrost unit places the coil and fan unit within an insulated box with a motorized door, or shutter, operation. During refrigeration, the door is held open by the motor operating the door mechanism. At defrost, the door is closed by its operating motor and the coil is completely contained within the insulated box. The fan continues to operate and electrical strip heaters placed in the air stream are energized. The air circulating over the heater elements is warmed and the warm air defrosts the normal refrigeration. This is a very positive method of electrical defrost for minimum defrost time and also for minimum transfer of heat to the cold room.

Electric defrost is quite widely used in small and intermediate sized plants. A minimum of maintenance is required and no alterations are required to be made in the refrigeration system itself. In larger installations with a multiplicity of cooling units, wiring and power consumption can be a factor as mentioned previously. A careful study should be made of the plant in question and all factors weighed as suggested before the adoption of an electric defrost system for the larger plant.

Hot Gas Defrost

Hot gas defrost involves the use of discharge gas from the compressors, the discharge gas being diverted from the conventional condenser to the various cooling coils located in the cold rooms. Condensation of the hot gas into a liquid in the cooling coil causes heat to be extracted from the gas and this heat melts off the ice and frost accumulated on the outside surface of the coil. Automatic valves are normally used to raise the pressure in the coils during defrost to maintain a condensing temperature above freezing to achieve ice meltage. A pressure relief valve should always be used to prevent coil damage from excess pressure. Various types of hot gas defrost are used in many plants from the smallest to the largest. It lends itself well to automatic operation and is economical in that it uses heat that is normally thrown away in the condensing system. Since it is actually an integral part of the refrigeration system, it responds to the same controls and safeties as used in the automatic control of the refrigeration system. It is a fast method of defrost since the heat is applied from inside the coil and exerts a uniform melting effect. In recent years, this type of defrost has come into favor in plants of all sizes and particularly in large plants using liquid recirculation systems since the discharge gas type defrost works extremely well with this type of system. In the small and intermediate plants, various patented systems are used where a single compressor and coil combination may be hot gas defrosted.

In large multi-machine and multi-coil systems, hot gas is applied to selected coils and the condensed liquid from defrost of these coils is distributed to other coils still under refrigeration by pump or other pressurizing methods. In this type of operation, the disposal of the liquid refrigerant from defrosting coils poses no particular problem if the capacity of the coils being defrosted is 25% of the total coil capacity operating in the plant. This is a maximum figure and lesser tonnages can, of course, be defrosted as desired. Defrost can be made entirely automatic and programmed so that selected coils are defrosted at various intervals and always providing the proper mix of coils operating and defrosting so the balance of the overall plant is not upset. This type of system is particularly adaptable to large ammonia systems and to some selected halocarbon systems.

Various schemes are employed in small hot gas systems. In one type of defrost the hot gas is condensed conventionally in the cooling coil to defrost the coil. The condensed liquid refrigerant feeds into an accumulator and thence through a small bleed port back to the compressor in very fine droplets. The heat of compression in the compressor dries the gas and it is again recycled through the coil, accumulator, etc., as long as required to defrost the coil. In another type a vessel containing water or some other fluid is heated by the discharge from the compressor during cooling periods. At defrost the condensed liquid from the hot gas defrost is led back through a coil in the heated fluid which evaporates the liquid into a gas which is then led to the machine suction and the compressor compresses the gas for another cycle through the evaporator of the hot gas. The two systems described above are generally used with halocarbon refrigerants. Other similar systems are also used. All seem to work well when properly installed and adjusted and lend themselves to automatic control.

Brine System Defrost

Defrost systems employing air defrost, water defrost and electric can be used on brine circulating system coils the same as with direct expansion coils. In place of hot gas defrost as in direct expansion, hot brine can be utilized for defrost purposes. Part of the brine charge of the plant is run through a brine heater. Quite frequently the brine heater is a heat exchanger mounted in the discharge of the refrigeration compressors and utilizing the heat from the compressed refrigerant gas to heat the brine before the gas enters the condenser. The coil, or coils, to be defrosted are valved off from the cold brine circulating system and the hot, or warm, brine valved to flow through the coil, warming the coil surfaces and thus melting off the accumulated ice. Hot brine defrost can be accomplished with hand valves or automatically with the use of solenoid or motorized valves. Normally the hot brine line is a small line fed by a separate pump from the brine heater to the coil locations and returned to the brine heater. In this way, selected coils can be defrosted without interfering with the operation of other coils operating with cold brine.

CONTINUOUS DEFROST

In a system employing continuous defrost, the coil may be either direct expansion or brine circulated. A low freezing point brine is continuously sprayed over the outside (airside) of the cooling coil to keep it clear of any ice formation by melting any ice as fast as it forms by dissolving it into the brine. The wetted clean coil surface has a slightly higher rate of heat transfer than a similar dry surface. The brine solution may be made up with common salt (sodium chloride) for cooler operation and particularly in meat coolers. Glycol solutions are used in many instances in freezer operations. In the salt solution in a cooler, as the unit cooler operates, the moisture in the air is condensed into the salt solution which will tend to weaken the solution by dilution. The brine solution is normally collected in a sump pan beneath the cooling units and to keep the strength at proper operating level, block salt is placed in the sump pan which gradually disolves into the solution to maintain strength sufficient to prevent freeze up of the brine. Excess solution is drained out by a pan overflow.

A more sophisticated patented version of the brine spray unit is used in freezer rooms. The pumped brine solution sprayed over the cooling coil is made up with a glycol base. As the brine is sprayed over the cooling coil, moisture is condensed so that there is a continuous weakening of the brine, the same as in the simple salt brine spray described above. However, in this system, the weakened brine from the coil sump is circulated through a concentrator which separates out some of the moisture by heat and returns a concentrated solution back to the cooling unit. A source of heat, usually steam, is supplied to the concentrator to separate the water from the solution and controlled to produce the proper density of brine. Several cooling units may be operated from one concentrator. Initial expense is relatively high for this type system. It has the advantage of full time coil operation with no shut down for defrost. The system is used, probably most effectively in areas where frost build up is rapid and difficult to control.

TIME DELAY WITH DEFROST

Some method of fan delay is most important when bringing freezer coils back into operation after defrost. The delay needs to cover the time period to cool down the coil surface to near or below room temperature. If the fans are turned on immediately after defrost while the coil is still warm, a quantity of warmed air will be blown into the cold room. The expansion of this warmed air will cause a pressure build up within the cold room and in a tightly constructed vault can cause structural damage to the walls, or in some instances, will blow open doors to the cold room. A bulb type thermostat with the bulb strapped to the suction line leaving the coil can be set to prevent the fan motors from being energized until the temperature of the coil is below the danger point. In some rooms, relatively large gravity closing vent dampers are installed. Any warm air pressure is relieved through these dampers to prevent pressure stresses on the room structure.

SUMMARY

In an automated plant, the selection of the proper defrost system to be used is important. Careful study should be given as to what defrost will give the best results in the plant being designed. In many instances, more than one type may be required to fully meet the needs of a particular plant. Almost all types of defrost can be made automatic but some systems may lend themselves better to automation than others.

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Operation and Maintenance of Cold Storage Warehouses

Warehouse operation can vary a great deal depending on a number of factors such as geographic location, items stored, special handling for specific requirements and many others. However, there are certain fundamental requirements that apply rather generally to all operations. These requirements deal with operation of refrigeration equipment, maintenance of materials handling equipment, maintenance of building, housekeeping, etc. Personnel required for these various operations can vary a great deal depending on the size of a warehouse, degree of automation and complexity of materials handling equipment. The following items are a summary of the most common use of personnel in the operation of warehouses in general. A considerable amount of record keeping is also necessary in mechanical operations of a warehouse in addition to the business records and some of these are also described. Records can become very cumbersome and those in authority should always strive to keep operational records and maintenance records as simple as possible, but in sufficient detail to tell the story desired from each set.

CREWS NEEDED FOR WAREHOUSE OPERATION

Certain crews must be set up in a warehouse operation. The duties of various crews will differ depending on the area, predominant items stored, labor agreements and other factors. Basically, cars or trucks must be unloaded, merchandise palletized and stored in designated areas in dry or cold storage as required. Merchandise must be accurately checked in and lot numbers assigned and all of these records transmitted to the record keeping facility. The reverse sequence applies when merchandise is shipped out of the warehouse. Merchandise should also be inspected and temperatures taken, when advisable, and any abnormalities duly noted. Some warehouses may specialize in large quantity movement of items while other specialize in small lot movements.

TRANSIT STORAGE AND DISTRIBUTION

Transit storage in which merchandise is stored in full carloads from some remote point for an interim period and then shipped out to a final destination has proved a popular form of storage over the years. Freight rates are adjusted to make this type of storage advantageous. Incentives have not been so great in recent times and transit storage is probably not in as great a use in most areas as it formerly was. Warehouses quite frequently can, and do, act as a distributing point for local shipments and also for transhipping in small lots from a large single lot in storage. There are endless variations in services that may be performed to the mutual benefit of both customer and warehouse and any agressive warehouse should actively seek out means of service that will better serve existing customers and also attract new ones.

MECHANIZATION

Almost all merchandise for storage is handled mechanically in the modern warehouse and the one story construction of most of the modern warehouses is oriented to this type operation. Forklift truck operation for handling merchandise is standard almost universally with other types of handling and palletizing equipment used in conjunction with the forklift trucks.

In large warehouses, loading and unloading crews are used for both rail car and truck operation. These crews may consist of from two men on up depending on the routine of the warehouse in loading and unloading. Checkers are also essential in keeping an accurate count of merchandise. Fork trucks work in conjunction with the crews to assure a smooth flow of merchandise in and out of the various assigned areas. Maintenance crews are also an essential part of the warehouse operation. In large warehouses, there will be found a constant damage and breakage as well as wear of mechanical items and an efficient maintenance crew is essential to the smooth and continued operation of any warehouse. Good maintenance is essential in all facets of warehouse operation, from the materials handling equipment through the equipment and even the building structure itself.

MAINTENANCE

Maintenance crews are usually designated for certain specific jobs. This designation is normally dependent on the local labor situation and the actual organization, or departmentalization of the warehouse. Ideally, maintenance crews should be multi used and able to pitch in wherever needed regardless of area or type of maintenance. Unfortunately, this is rarely accomplished and maintenance crews are usually divided into various areas of warehouse maintenance work.

MACHINE ROOM MAINTENANCE

Machine room maintenance of the most effective type is that referred to as preventive maintenance. This is a positive type of maintenance in which machinery is checked before trouble develops and minor ills are diagnosed and repaired; thus preventing, to a great extent, expensive and time consuming breakdowns. If preventive maintenance is followed religiously, failures or breakdowns of any type should be rare rather than a common occurrence. Too often, routine preventive maintenance is neglected or not even considered until a breakdown of major proportion occurs with all its attendant ills; excessive down time, expensive repairs or even equipment replacement, etc. These repairs and replacements are very expensive and time consuming and the preventive maintenance to largely eliminate such happenings is not difficult to accomplish and is relatively inexpensive when compared to the repair and time costs it can prevent.

The chief engineer or another designated individual should have a full set of records on all major pieces of equipment in the plant concerned with refrigeration. These records should contain a full description of the equipment with appropriate serial numbers. Spare parts lists should also be on file to be used in connection with the records of the equipment. This record should also contain oiling or greasing periods and other pertinent information about the equipment. If the equipment is of the type that needs to be inspected or overhauled at stated intervals, this information should also be contained in the records as well as space to indicate the date of the performed service. It should be the duty of the maintenance crew concerned with the machine room to perform the required preventive maintenance as required and to conduct routine overhauls of the machinery.

The importance of maintaining lubrication, inspection and overhaul records cannot be overstressed. These records should also indicate when the work was done, not just that it should be done. Overhaul procedures may include a minor or major overhaul. The time periods should be worked out and indicated in the records mentioned above. It is possible, that in some instances, too much maintenance in the form of major overhauls is performed on machinery, when only a minor overhaul and thorough inspection are all that is actually required. Preventive maintenance is important in any plant but care should be exercised that the periods of inspection and overhaul are kept reasonably spaced and not performed oftener than is required to assure good operation. Large heavy duty equipment will perform well over long periods of time with only minor inspection and attention. It is sometimes less expensive to bring in an outside crew for major overhauls rather than maintain an internal crew for this purpose.

A master chart, readily available to maintenance personnel, is desirable. This chart should list the oiling and greasing specifications for all of the plant machinery as well as the lubrication interval. Blank spaces should be included in the chart in which may be written the date that lubrication was actually performed for each item of equipment along with the initials of the person actually performing the lubrication. In a large plant, such a chart can be quite lengthy and may require multiple pages. The larger the plant, however, the more important such a guide becomes since the large plant usually has a large number of motors and rotating machines in operation and many of them scattered in remote sections of the plant. Without some method of keeping records of the lubrication periods, some motors or machines are bound to be neglected and even forgotton with a subsequent loss due to bearing failures from lack of proper lubrication. Charts on all machinery that must be inspected and overhauled or be lubricated at stated intervals are good insurance and also a valuable record to indicate that maintenance or lubrication has been performed at the proper intervals. The matter of overhaul by plant personnel or outside help depends on the crews kept available within the warehouse. Minor overhauls and final inspection of major overhauls should certainly be within the authority of the plant maintenance crews and the chief engineer or his assistant.

OPERATION RECORDS

A set of operating records is almost mandatory in a large plant. Too many operators ignore temperatures and pressures of various items of equipment. In the refrigeration cycle, a set of temperature and pressure readings can tell a great deal about the operating efficiency of the plant. In the design of any plant, it is important that adequate thermometer wells, gauge connections and other adjuncts for taking readings by incorporated in the design so that a full set of pressure and temperature readings may be taken as desired. This data may be taken by direct reading of the various instruments or on recording instruments. No matter how the data is taken, it should be reviewed constantly as a comparison of plant operation. Deviations from the normal readings should be investigated at once since these may indicate trouble. This review of the data is normally the job of the chief engineer, or his assistant, and it is he who will investigate and direct whatever action should be taken. A word of caution should be interjected on the taking of various data readings in and around the plant. By all means, take all of the essential readings so that a complete operating performance of the plant for analysis may be made from the data taken but do not clutter the log sheets with data not necessary and not germane to the plant operation. If certain readings are taken visually by plant personnel, explain why they are necessary and the importance of accuracy and it is a safe bet that, once the reason for data is known, more care will be taken to achieve accuracy.

OVERHAULS

Cold storage room units will operate over long periods with no major overhaul but they whould be checked periodically and fan and motor bearings of evaporators should be lubricated at stated intervals. It is also important that the correct grade of lubricant be used in cold rooms, particularly freezers, since improper types can congeal and cause bearing failure. Other types of lubricants not suited for cold operation can lock bearings and cause motor troubles.

CHEMICAL TEST OF SECONDARY REFRIGERANTS

In plants employing brine systems, periodic checks of the brine pH value and density should be made and the necessary treatment added to keep a brine that is neutral and to prevent any corrosion. In addition to keeping a neutral brine, it is important that the density of the brine be kept at a reasonable point. The density should be kept to the minimum consistent with the lowest temperature expected in the brine system. As brines become more dense, particularly calcium chloride brine, the pumping horsepower becomes greater. Also the specific heat of the brine solution decreases so that more volume of brine must be pumped to perform the necessary refrigeration. This results in increased power required and higher operating cost. If the brine density is carried at a density of too high a point over the design conditions, plant temperatures become difficult, if not impossible, to maintain.

ROOM TEMPERATURE CONTROL

Room temperatures in the cold storage plant are important and a record of these temperatures at regular intervals is important. Customers pay for storage at certain temperatures and it is up to the warehouse to maintain these temperatures. Most modern cold storage plants do a good job of maintaining temperatures and the best proof of the temperatures held is a strip chart or other recorded data of temperatures in the various rooms. A good temperature recorder that automatically records temperatures in the various rooms at stated intervals is a good investment and a necessity in most plants since it affords a permanent record. This type of temperature record keeping removes many doubts that might exist as well as inaccuracies that creep in with a manual-visual method of taking temperatures. In some specialized rooms, the relative humidity may also need to be recorded. This is usually done with an isolated recorder serving one area only.

In larger plants, there are usually operating crews and maintenance crews. The operating personnel are on duty to see that the refrigerating and allied equipment operates properly. This crew can be divided for 24 hour operation in plants requiring constant supervision or where required by law. In completely automated plants, operating crews can generally perform necessary tasks during business hours so that only skeleton personnel may be used during non-working hours. Completely automated plants will normally operate without trouble with no attendants during the times when the plant is not in business operation especially when equipped with an alarm system to inform standby operators if trouble develops. Operators on duty at automated plants should be of topflight ability and with a complete understanding of the plant and its operation. The maintenance crew for the machine room should work in close cooperation with the operating personnel so that a close liaison is maintained at all times to keep the plant in top operating condition. The maintenance crew should be familiar with all of the machinery and also have electrical personnel who can service the control system as well as the plant electrical power and lighting systems. In smaller plants, many of the maintenance services required can be performed by outside service companies; but as plants grow larger, in-plant crews are usually favored. In smaller plants, and even in some relatively large ones, maintenance crews may serve multi-purposes by working in all areas of the plant and thus allowing a labor pool for use in case of an emergency in any part of the plant. The use of these multi-purpose crews depends greatly on the policies set up as well as labor contracts and other pertinent influencing factors.

GENERAL MAINTENANCE

The general warehouse maintenance crews are those who perform maintenance and repair on material handling equipment, warehouse equipment and building repairs. The size of the house will generally determine the size of the crew. No two warehouses will operate in exactly the same manner so that the number of personnel of crews will differ from one warehouse to the next. Fork-lift trucks require rather constant maintenance. Most warehouses with cold storage will operate battery powered fork trucks in cold rooms due to the hazards of exhaust gases from internal combustion engines in tight rooms. Batteries require battery chargers and the chargers require electrical maintenance. A considerable amount of motorized equipment is used in most warehouses so that a small crew is usually employed on the maintenance and repair of this type of equipment. Warehouse property itself is subject to abuse. Automatic doors are quite frequently hit and jammed. Walls can be damaged from fork trucks and other equipment and there is a constant requirement for maintenance and repair of building items. Some of the building crew can sometimes also be used in a carpenter shop for the repair and maintenance of pallets used in the cold and dry storage rooms. Pallets get broken quite frequently and this item, in a large plant, can provide rather steady work for a small crew. As in machine room maintenance, complete records should be available for mechanized equipment including spare parts lists, overhaul information and general instructions sheets. Running records on equipment such as overhaul, repairs and greasing should be maintained so that information is available when needed for comparison purposes or determination of work schedules on various items of equipment.

CLEANLINESS IN FOOD STORAGE WAREHOUSES

General housekeeping requires a few individuals and some mechanized equipment for sweeping and also, in some plants, trash hauling equipment. The maintenance of neat clean premises is an important feature in any plant. Large plants can accumulate a considerable amount of waste material that must be disposed of and it is no small task to keep a plant neat and clean. Rodent and insect infestation is to be avoided at all times. Control of this type of infestation is generally handled by an outside professional organization who has the necessary equipment to do a proper job. Constant vigilance is needed to keep premises clear of unwelcome guests.

There are other areas requiring maintenance such as painting, office maintenance, etc. These areas are quite often handled by outside contracts rather than with plant personnel.

MAINTENANCE AND REPAIR RESPONSIBILITY

All of the maintenance and repair work should be coordinated by one individual so that the work load may be spread evenly and equitably between various departments. This individual, quite frequently, is the chief engineer. It is his responsibility to see that the plant operates and functions as it should and to coordinate with the various sections of the plant to do maintenance work when it will be the least disturbing to the general operations of the plant. It should always be borne in mind that the plant is operated to the end of making a profit or it cannot operate. This profit can only be achieved by having satisfied customers. Maintenance is important to keeping the customer satisfied and is a good tool in the overall operation of the plant.

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17

Record Maintenance in Cold and Freezer Warehouses

Operation of a cold storage facility can range from a very simple private warehouse to a large complex public warehouse. Records are of extreme importance regardless of the operation and size of a warehouse. Many systems are used and usable for record keeping from a simple bookkeeping machine to complete computerization of all records including general ledger entries for the complete operation of a facility. In some installations, orders are received in a central location and transmitted electronically to the various work bays for filling; inventory records are also adjusted from the order filled so that the customer has available at any time, a complete inventory record as well as any other data he may require concerning his merchandise in storage.

There are numerous texts and explanations of various record keeping systems and methods and it is not the purpose of this volume to enter this phase of warehousing in depth. So many different variations exist in the record keeping field that it should be studied by the prospective owner or operator and a system put together that will fully satisfy the needs of the particular operation.

The cold and freezer refrigeration warehouse as a privately owned, public agency, has obligations much beyond the quarterly reporting to its board of directors. From the organization standpoint, the management must keep the Internal Revenue Service informed at least annually of all of its income-outgo. Since they are handling food in large quantities, usually on the contract basis, both in transit and for local delivery, they must keep adequate records for the Food and Drug Administration, for the U. S. Department of Agriculture, and Commerce, and Interior.

Within the larger family of cold and storage warehouses of the United States they should maintain close contacts with the National Association of Refrigerated Warehouses, Inc., Washington, D. C. This association maintains general contacts with its member warehouse managers through the "House" monthly magazine.

WAREHOUSE RECORDS

The operation of a cold storage warehouse does not vary greatly whether the operation be public or private. In record keeping, however, there is a considerable difference. In private warehousing, records are kept purely for the benefit of the individual owner whose merchandise is stored in the warehouse and the record system is usually tailored to his individual needs.

In public warehousing, records are maintained by the warehouse owner, or operator, for the benefit of the many customers who store merchandise. These records must be accurate and up-to-date at all times. Variations in service available to customers are almost endless. Services can include inventory control, shipping, pool car shipping, transit storage, special handling and many others depending on the desires of customer and owner or operator. The warehouse has the responsibility of keeping accurate records as to the customers merchandise in storage. These records,should contain complete information of the nature of the stored product; temperature of storage; where it is stored and in what quantity. As merchandise is withdrawn or added, the records should so indicate and a balance made available to the customer showing the status of merchandise as to quantity in storage. In small and medium operations, these records can be kept by simple methods from hand prepared sheets to bookkeeping machines without too much difficulty. As the operation of a warehouse expands to larger quarters, more complicated systems are required and in the largest warehouses, some type of computer system will undoubtedly be needed to keep pace with expanded service. With this type of record keeping, almost any information relative to stored merchandise is available on short notice. Inventory records are normally the base information fed to the computer. These records are stored including additions and withdrawals for ready reference whenever needed.

THE RECORD SYSTEM

There are many systems of record maintenance and reporting available on the market for American managers of cold storage warehouse enterprises. Unless the president or executive manager of any industry is himself a certified accountant or an auditor of experience, he should not attempt to design a system that will meet the approval of the taxing and banking agencies with whom the warehouse must cooperate for his operations and his financing.

Most acceptable auditing firms have their own forms, system and auditing sheets, that they have found most useful in serving in their capacity as certified public accountants and unless the business has an already going established record system that has been found most adequate, any new or replacement system should be introduced with the full cooperation of the accountants concerned.

Helpful recommendations and suggested systems for refrigerated warehouses accounting can be obtained from the National Association of Refrigerated Warehouses.

RECORD MAINTENANCE

In the supervision, maintenance and operation of any business, record keeping is not only a requirement now imposed upon all industry and businessmen by the Internal Revenue Service, but has been for several generations one of the principles specified for the successful, efficient, operation of any industry that expects to compete successfully.

While cold and freezer storage warehousing may or may not have within their daily activity, manufacturing of products as such, there is an obligation to maintain a very exact income and outgo of all products, labor, electrical energy, office keeping and the obligations they have accepted in the storage liabilities within their business enterprise. These records should be kept from the first day they take over the ownership and supervision of the cold and freezer storage business. Some of the more critical items of which the records should be maintained, include: (a) the cost of the money required in establishing the business; (b) meeting the daily payrolls; (c) cost of equipment and materials to keep the warehouse operating efficiently; (d) the outlay for maintenance; (e) continuing repairs; (f) power, light and air conditioning; (g) the cost of salesmen of general personnel and department management; (h) city, state and county, and Internal Revenue taxes available when demanded by the several agencies; (i) the cost of accident, fire, tornado and theft insurance, a continuous cost of owning any industry.

The every day cost may be divided into two main categories: (1) owning; and (2) maintenance and operation. The owning will include amortization, interest and insurance.

A breakdown of the operating expenses will include all energy demands, all maintenance, operating personnel, management personnel and all utilities service.

SERVICE AND ENERGY COSTS

In the annual audit very exact accounting of all power and lighting is essential; these costs are very often related to the material cost of water, gas and oil, depending upon the source of power utilized by the management. It is also important, in some instances, to establish power requirements for the refrigeration plant for the freezing of products as opposed to straight storage. There are many instances, where certain taxes may be waived in the case of food processing and some states may consider freezing as a form of processing. Savings can, therefore, sometimes be effected with a sound logical breakdown of power costs used for this purpose; or other related purposes in the warehouse operation.

AIR, WATER AND SEWERAGE CONTROL

This item is becoming a very important issue in every one of our modern cities. New regulations are constantly being added limiting the use of water supplies, controlling air pollution and sewage and imposing stiff penalties for noncompliance. Prudent management will see that control is maintained in these areas. Every manager of a cold and freezer warehouse, especially those permitting food processing on their premises, should be certain that his plant design includes a satisfactory method of sewerage clarification that will meet municipal, state health and national requirements as prescribed by law.

OPERATIONAL AND MANAGEMENT SALARY SCHEDULE

In the successful management of cold and freezer storage enterprise there is no place for "window dressing" salaried employees. The budget of a well operated enterprise in the cold and freezer storage industry to be competetive must be organized anticipating that from the manager or owner to those employees assigned to cold rooms, docks, and to the maintenance of records and similar clerical assignments, these are all performed by active "working" personnel.

The items that must be recognized in the monthly and annual work sheets for the Management and Operation of Cold and Freezer Storage Warehouses are given herewith in Table 17.1.

MANAGEMENT AND OPERATING COSTS RECORDS

Many business failures in the operation of cold and freezer warehouse enterprises can be laid upon the failures to anticipate all of the operating and management costs that accrue from the amortization of the original investment and to the annual monthly repetitive costs of doing business on a scale acceptable to the public.

TABLE 17.1. ITEMS THAT MUST BE RECOGNIZED IN THE MONTHLY AND ANNUAL WORKSHEETS FOR THE MANAGEMENT AND OPERATION OF THE COLD AND FREEZER STORAGE WAREHOUSE

(1)	Investment Amortization (after annual)
	cost of storage facilities cost of mechanical and electrical system cost of the management facilities
(2)	Annual Overhead
	interest income taxes (IRS) property taxes insurance rental charges
(3)	Maintenance Costs
	replacements water and oil painting refrigeration salaries of maintenance men
(4)	Service and Energy Costs
	power for pumps power for refrigeration machines power for fans lighting and miscellaneous motors
(5)	Material Costs
	water gas fuel oil other oils
(6)	Air, Water and Sewerage Control and Clarification
	air filtering and cleaning water treatment sewerage disposal and clarification
(7)	The Operational and Management Salaries

Auditing Control and Amortization

The manager and/or owner of any cold and freezer storage warehouse must maintain comprehensive cost accounting procedures. They should be set up so that the owners may recover each year a portion of the initial cost as an expense item charged against revenue. This decrease in the value of property should be determined by the company auditor in conference with the Internal Revenue observers and all US Government control agencies related thereto officially delegated to control the quality of food, disposal of rejected foods, and sewerage and the financial structure of the corporate setup. The auditor and the management should have full agreement with the Internal Revenue observers, banking interest, and Federal agencies assigned to protect the public interest in the affairs and procedures of the food dispensation and storage. In all of this

TABLE 17.2. RECOMMENDED DEPRECIATION PERIODS[1]

Item	Years
Air conditioning systems	20
large—over 20 tons	20
medium—5 to 15 tons	15
small—under 5 tons	10
Air washer (see Dehumidifier)	
Compressors	
air	20
Condensers	
double pipe	20
evaporative	15
shell and tube	20
Coolers, water-tank and coil or shell and tube	20
Dehumidifier	10
Drums, purge or surge	20
Ducts and other sheet metal work[1]	± life of building
Engines (gas, diesel or dual fuel)[2]	20
Fans	15
Filters, air, oil, self-cleaning	20
Gages	15
Heaters	
gas	15
water heaters, open or closed type	20
Heating systems	
boilers and furnaces	20
Insulation	15
Motors	
induction indoor	20
induction, weatherproof for outdoor	20
Synchronous and exciter set	20
Piping, refrigerant and other	20
Pumps	20
Receivers, refrigerant	25
Spray pond	15
Switchboards, electric	25
Thermometers, room type or recording	15
Tower, cooling	15
Transformers	25
Turbines[2]	20
Valves	
relief	20
automatic expansion and by-pass	5
water regulating	20
Wells and well pumps	25

[1] From system evaluations studies by W.R. Woolrich and E.R. Hallowell.
[2] Estimated values, not IRS values.

the auditor and management should give careful consideration to the amortization of the plant and facilities.

Some items that must be included in amortization that may determine the length of period agreeable to all, are: (a) type of building and its useful life; (b) type of equipment, and (c) the lease or ownership conditions.

Annual Overhead.—This item is primarily the interest that must be paid annually and the tax items that must be paid both to IRS and the property taxes due the city, county and state, plus the insurance and rental obligations annually recurring.

Maintenance Costs.—The manager of any cold and freezer storage plant should recognize that he is in a commercial enterprise that is highly competitive and the maintenance of his plant can be one of his best advertisements.

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Lighting and Electrical Facilities and Prime Movers

Lighting for cold storage rooms presents problems that are not ordinarily considered in the selection of lighting systems. The light source must be able to start and maintain itself in temperatures as low as −30° F (−34°C). Blast freezers may require even lower temperatures. Light sources should have a long life since the labor cost of replacement is high in that it requires work in a cold room stacked high with merchandise and high ceiling lights are often very difficult to reach. Economy of operation is also a large factor in the selection of lighting equipment since lights are quite often left to burn continuously, either accidentally of by design. With almost constantly rising energy costs, economical operation of light sources is extremely important. Plant planners and builders should well consider all types of lighting. Higher initial cost for equipment can sometimes result in lowered operating costs that will justify the higher initial outlay.

FOOT CANDLE - LUMEN

One foot candle is a measure of illumination on a surface which is 1 ft distant from and perpendicular to a source of illumination of one candle power. The foot candle and lumen are interrelated in that one lumen is the unit of light flux representing a quantity of light falling upon 1 sq ft of surface, every part of which is 1 ft distance from a point source of one candle power. The scientific foot candle or "candle foot" is defined as "the illumination produced by a British standard candle at a distance of 1 ft."

Watt rating is a unit of electrical power for classifying lamps by electrical consumption. A 40 watt lamp will require 40 watt hours per hour of electrical energy if burned continuously.

Light sources are commonly expressed in lumens output and thus the efficiency of a light source is dependent on the lumens of light output per watt of electrical energy input to the light. A light with high lumen output per watt can obviously cover a larger area with light than the low lumen source light. This does not take into account the quality of the light which can also influence the type of light source used. Where possible, the high lumen output per watt light is desirable and more efficient and economical to use.

LIGHT AND VISION

Light excites the sensation of sight and must fall on objects if they are to be seen. Shadows are formed by objects that cut off the rays of light, thus creating shadows. Illumination from a light source decreases with distance to the law of inverse squares. As the distance from a light source is doubled, the illumination produced is 1/4. If the distance is again doubled, or increased to four times, the illumination is reduced to 1/16.

AVAILABILITY OF LIGHTING EQUIPMENT

There is no really effective standardization of lighting equipment. There are numerous types of lighting equipment on the market that can be used in cold storage warehousing. Some of these are: (1) the incandescent filament lamp; (2) the fluorescent lamp; and (3) the high intensity discharge lamps including sodium, metal halide and mercury vapor lamps. There are also some other types of lighting that can apply to industrial use. The high intensity discharge lamps as well as fluorescent lamps all require a ballast of some type for proper operation. The newer sodium lamps have a very high output in lumens per watt as well as a long life span. The long life and high lumen output per watt and their ability to operate over a wide temperature range make the sodium light a desirable consideration for illumination in the cold storage facility. It can be used for interior as well as exterior lighting. Color definition is not too good with the sodium lights but is quite often considered adequate for storage rooms, docks and other applications. Many new installations are being designed for this type of lighting as well as older systems where retro-fitting is being considered for power savings in lighting. The metal halide light can be used where better color definition is desired. Mixtures of various types of light sources are sometimes used to obtain special effects and where color definition is important. Mercury vapor lamps have value and good color definition and good efficiency although usually not as high as the sodium lamp.

Many needs for lighting around a cold storage plant such as stairways, loading platforms, entry ways and machine rooms can well be illuminated with simple less expensive equipment. This selection, however, can change as energy costs rise and the better, more efficient lighting may be found to pay off even for the more obscure lighting tasks.

Within cold storage warehouses, the lighting is much different from most industrial applications in that there is no natural light within the rooms, thus the best and most effective in-plant lighting with minimum shadows and heating with maximum illumination are the most acceptable.

The closest approach to natural light is probably obtained with fluorescent types of equipment. In some storage areas where rigid inspection of merchandise may be required and in other specialized areas where color definition must be good, fluorescent lighting may be used as the efficiency of this lighting is much higher than the incandescent light but normally, not as high as the high intensity discharge lamps. Fluorescent lighting gives good results in dry storage, cooler and freezer storage. Special jacketed tubes are used in cold temperatures and with this type of tube, lighting intensity is very good. Fluorescent and high intensity discharge lamps may be installed using 277 volt circuits obtained from a phase to neutral in a 4-wire, 480-v system. This eliminates the need for localized transformers for lighting in 480-v plant electric systems. Lighting breakers are rated at 277-v instead of the normal 115-v. Eight foot fluorescent tubes, where mounted high out of the way of mechanical damage are frequently used for illumination, both inside storage rooms and outside as well as external locations from the rooms. Tubes can be used either with or without reflectors depending on the design of the lighting system. In using fluorescent lighting in cold rooms, the proper ballast should always be selected and this ballast may be a variance with the standard ballast normally used in interior lighting.

HEAT LOAD

Lighting in a cold storage room provides a double penalty for inefficient use. In addition to the energy used for illumination, sufficient additional refrigeration must be provided to remove the power input to the lights as it degenerates to heat energy. Each kilowatt of lighting energy used in a cold room will generate 3412 Btu of heat that must be removed from the room over and above the other room losses. It can be seem from this that for each 3-1/2 Kw of lights burning, approximately one ton of refrigeration will be required to remove the heat generated by the lighting. The refrigeration cost should be taken into account when lighting costs are being evaluated. The more lumens per watt, the less heat load on refrigeration equipment for a given lighting intensity.

LIGHTING SYSTEMS

The development of lighting systems for artificial lighting is continually changing, and with the current energy prices, is shifting to offer more efficient lighting and methods of reducing light use without hazard to health. In view of these conditions and the rapidly changing methods of lighting, it is always well to consult with a competent lighting expert when designing a new facility or modernizing an existing one. By consultation with someone who is thoroughly familiar with various types of lighting systems and with the peculiar warehouse lighting problems and is also keenly aware of economy needs, much time can be saved as well as trial and error installations avoided. In a large warehouse facility, lighting power costs can be a considerable portion of the electrical cost of operation and it is extremely important to obtain a design effecting the best economy and still retaining adequate illumination.

SAFETY ILLUMINATION

A cold storage room with all doors shut and all the lights turned off is a complete example of total darkness. When caught in such a situation, an individual can become very much directionally confused and lost even in a relatively small room with resultant panic and possible injury from running into objects in the dark. To avoid this possibility, it is a good plan to place one circuit for lighting in each cold storage room, or any room that can be tightly shut to exclude light. This circuit should have no local control switch so that it will always be alive. Only one or two lamps of small wattage are necessary, since even a candle lighted in pitch blackness will produce enough light to indicate the way to an exit. The safety lights should be served from a completely independent lighting circuit and the lights should have a regular check to see that they are operating. Emergency battery operated lights can also be used to good advantage if a regular maintenance check is instituted. They normally act as auxiliary illumination on power failure of a main source and are wired to turn on automatically in the event of such a failure. Batteries are maintained to strength by a trickle charger during regular warehouse operation. The main disadvantage of the auxiliary light is its lack of maintenance. Since there are normally long periods without power failure, the emergency light maintenance and checking tends to be forgotten. In addition to safety lighting in cold rooms, doors should be provided with an emergency release from the inside so that anyone trapped inside a cold room may escape from the room even though the doors are in a locked position. Most insulated industrial cold room doors are equipped, or can be equipped, with such a device.

OUTSIDE LIGHTING

Most cold storage warehouses will work into the night hours, at least on some occasions, and adequate dock and work space lighting should be provided so that work may be done efficiently. In these areas, high intensity discharge lamps including the sodium and mercury vapor lights may be used to good advantage. Portions of these lighting circuits can also be used for security lighting during periods of non occupancy. These lights are quite frequently operated on 277 volt circuits.

BLAST AND SHARP FREEZERS

Blast and low temperature freezers will normally require incandescent lighting since the temperatures are usually too low to be favorable to other types of lighting. This is particularly true where high air velocities are present. Lighting requirements in this type of situation are not great. The lighting circuits for incandescent lamps are usually obtained from dry type transformers located in various areas of the plant. Whenever incandescent lights are used, longer life than normally expected can be obtained if a lamp with a voltage rating somewhat higher than the operating voltage is selected. An example of this would be to use 130 volt lamps on 115 or 120 volt circuits.

RATES FOR ELECTRIC SERVICE

The cost of electrical current is based on many different factors and these factors will vary from one utility company to another. These costs include the capital invested, a factor of readiness to serve, the time of day of use related to the overall company demand for that period, the relation between demand and the amount actually consumed within a given period. All of these factors and more enter into the rates prescribed in an electric contract. A rate may sometimes be lowered by off peak loading.

Present escalation of electrical rates in almost all areas of the country make any explanation of rate structure somewhat difficult since it is changing constantly as electrical power company costs increase. Each power contract should be examined with care since power costs are one of the main expense items encountered in any cold storage facility and every effort should be made to determine that the plant is operating on the most advantageous rate schedule that can be applied. A competent analysis of the rates submitted is very much worth the expense involved and the best available advice should always be sought.

ELECTRIC LIGHT AND POWER WIRING

Cold storage plants utilizing commercial power are normally supplied with three phase power and at voltages of 220v, 440-480v or 550v. Probably the most common voltage is 440 or 480v 3-phase, 4-wire with a potential of 277v between any phase and the neutral or ground. With this type of system, all components are standard and are readily available without premium costs. Wire sizes are not excessive and most electrical contractors are thoroughly familiar with this type power distribution and the installation presents no unusual problems.

Power is normally supplied by the power company to the cold storage facility through a bank of transformers serving only the cold storage plant and normally at a single voltage. Wherever possible, two incoming sources of power are desirable, connected to the transformer banks through an automatic transfer switch. If power failure occurs on the high line normally serving the transformer bank, the second source is automatically switched to feed the bank and the primary source cut out. On resumption of power to the primary source, it automatically resumes service to the plant. This type of protection tends to prevent any prolonged outages of power.

The incoming power from the power company transformer bank will normally connect directly to a load center. The load center may be custom built for the particular job it serves or made up of standard purchased components. In the load center will be the main incoming switches. Smaller plants may be equipped with one main incoming switch while larger plants may have multiple main switches to divide the load into manageable portions. The number of main switches permissible should always be checked against national and local codes and the code adhered to strictly. It is good practice to use less than the maximum switches allowed to permit future growth. All main entrance switches, particularly of importance when served by large network power sources, should be protected by high interrupting capacity fuses made especially for this type of service. Ground fault interruption should also be included in the incoming switching. These items are usually code requirements but should always be included whether required or not. Sizes of incoming switches will vary from plant to plant and various combinations should be checked along with their attendant bus connections for the most economical combination.

Each main entrance switch will normally be connected to a number of separate feeder switches by busway connections in the load center. The feeder switches normally fall in the size range of from 200 to 600 amp and from these switches, the various components of the plant electrical system are fed. These components consist of electric motors, control apparatus, lighting, battery chargers and all other electrical equipment installed in the plant.

When the plant load center is located in the machine room in an automated plant, the automatic control panels are quite often made a part of the main switchgear in that the cubicles containing the control circuits and electrical switching relays adjoin the power cubicles to make a continuous panel system. Sometimes gauges and indicating instruments, etc., are also added to the control panels as well as indicating alarm systems so that the load center actually contains the entire electrical system center for the entire plant. Control wires for compressors may be run in the conduits carrying power to the compressor motors to pick up the various safety and operating devices located at the compressor and driving motor assembly.

Most designers find it desirable to use a voltage different from the power voltage for the control circuits with 115 or 120 v being a popular choice. A control transformer can be mounted in one of the control cubicles to supply control power at the desired voltage for the entire refrigeration system control. By utilizing this single source of control power through a magnetic contactor, a desirable safety feature of shut off may be made available. By means of a control toggle or other type switch mounted at the entrance to the machine room, the entire control system may be shut off without entering the machine room. With fail-safe controls normally used in automatic control systems, the entire plant can be shut down without entering the machine room. This is a very desirable feature in case of fire or a bad refrigerant leak.

From the central panel, or load center, power is normally distributed to the machine room and to the entire plant. Various circuits are run to wherever is necessary in the plant to supply power and lights in the various areas. As a general rule, all circuits are run from the load center at the plant voltage to the various locations. If a different voltage than the plant voltage is required at a particular location, dry type transformers are used to supply the divergent voltage. Battery chargers and integral horsepower motors will usually be operated at plant voltage in the 480-v supply system. Fractional horsepower single phase motor leads and incandescent lighting will normally require a 115- or 120-v circuit. From a 480-v plant system, dry type 3-phase transformers may be used to supply 208-v, 3-phase, 4-wire service for both single and 3-phase loads. These transformers will most often be sized from 25 kva to 75 kva depending on the load to be served. Leased spaces will also require special attention and transformers for the power peculiar to the type of equipment in the space. Quite often 208- or 220-v 3-phase as well as single-phase power will need to be available for special processing equipment.

In some very large plants, arrangements can be made to supply power from the power company mains in more than one location with separate transformer banks but all metered as one power source. This type of installation can prevent extremely long runs at plant voltages and permits a considerable saving in wiring and also in power losses from the long power lines. This type of installation should always be checked out with the local power company as well as the local code authorities before any designs are made final. This type of installation requires careful cooperation with all concerned but can lead to considerable savings when properly engineered and installed.

All electrical wiring in the plant should conform to the national and local electrical codes for safe wiring. In designing an electrical system, it should be remembered that the electrical codes are based normally on the minimum safe installation and are not concerned with maximum installations. When installing an electrical system, the sizing of main and branch circuits should always be done generously. All plants, if successful, tend to grow over the years and wiring should never be put in for minimum use. Where warehouses cover large areas, supply electrical lines in the plant should always be checked for voltage drop as well as load carrying ability. Quite often it will be found that long supply lines will need to be considerably larger than required for current carrying capacity to prevent too high a voltage drop. In running long power lines it is advisable to check out cost of multiple conductors over a single conductor per phase. Most codes will allow the use of conductors in parallel when certain installation rules are followed. Multiple conductors will quite frequently show a considerable savings over a single conductor of equal current carrying capacity.

Extra care should be used when running electrical connections through insulated walls into a cold area. Careful seal-offs with good sealing compounds is required to prevent trouble at some future date. This is particularly true in freezers.

Power factor correction will sometimes be required in plants utilizing a large number of small fractional horsepower electric motors. This can be rather easily accomplished by the use of a capacitor across the terminals of the motor. These capacitors will usually be of a production type that are relatively low in first cost; correction is applied at the motor where needed and the resultant reduction in current in the lines can save in wiring costs.

The layout of a complete electrical system for a cold storage plant is quite complicated. A great multiplicity of circuits is required, particularly in the modern automated plant. Careful preplanning of the system with generous wire sizing can save much grief and expensive rewiring.

In most areas it is necessary to obtain a permit from city, county or state authorities before a building or wiring may be started. A set of drawings depicting the proposed installation is usually required before a permit will be issued. The fees charged for permits generally are used to help defray the expenses of inspectors whose work leads to a safe, properly installed jobs. Power companies usually are not permitted to furnish power to an installation until a satisfactory inspection and report had been made by the inspecting authority.

TRANSFORMERS

The transformer is an electrical apparatus, usually without any moving parts. It transforms alternating current voltage from a higher to a lower, or from a lower to a higher degree. Usually it is made up of a special soft iron core and two electrical circuits called primary and secondary. The fundamental equation of the transformer is

$$\frac{\text{current in the primary}}{\text{current in the secondary}} = \frac{\text{number of turns of wire in the secondary}}{\text{number of turns of wire in the primary}}$$

Voltage transformation is directly proportional to the number of turns of wire in the primary and secondary. Transformers may be built in numerous configurations, depending on their specific design but all will follow the ratios above.

The rating of the transformer is predicated upon the heat generated in the windings and the associated iron core. In the design of a transformer the heating must be balanced against the ability of the surfaces of the transformer to dissipate its heat. To expedite this heat loss, most large transformers have their windings immersed in a special transformer oil for faster heat transfer.

Provision is made to cool the oil, either by means of a water cooling circuit or forced or natural draft air cooling. Oil sometimes can produce a fire hazard in certain transformer locations. In such cases, if air cooling does not suffice, some noninflammable liquid is substituted for the oil.

Transformers are usually installed in cold storage plants to reduce the main plant voltage to a usable voltage for appliances, incandescent lighting, power tools, etc. Sizes of 25, 50 and 75 Kva are relatively common utilizing a dry type transformer which is air cooled and requires no cooling liquids. This dry type transformer is usable in many locations. Transformers for local or spot use can be installed for both single and three phase service depending on requirements and design of the system. All code rules pertaining to the installation of transformers should be followed as a minimum requirement.

ELECTRIC MOTORS

Introduction

Electric motors perform a myriad of functions in a cold storage plant from a motor of several hundred horsepower driving a large compressor to a very small fractional horsepower motor operating a valve or damper mechanism. One of the virtues of an electric motor is reliability and its ability to plug along for long periods of time without failure. This reliability can also be a handicap. Since electric motors perform without fuss, they are often neglected from a maintenance standpoint until a failure occurs which, in extreme cases, can shut down an entire plant. Special efforts should always be made to perform routine checks and maintenance on electric motors. This should include lubrication when needed as well as cleaning and a good visual inspection.

Control Motors

Control motors are very specialized and usually well hidden in a plant since they are used in out-of-way places for various types of control. They are utilized wherever limited rotary motion is required, either directly or through a linkage arm of some type. Operating voltages of 24, 115 and 230 are common depending on the plant control voltage used. They are generally of very small power rating being often rated in watts rather than horsepower.

Control motors can be designed so that they revolve only a portion of a full turn, such as a damper or valve motor which may only revolve a half turn, more or less, from a full closed to a full open position. Other forms revolve very slowly through a gear train to perform a variety of control actions triggered by switches operated from a common shaft of the geared down motor. Almost all control motors are reversible so that their control action may be either forward or backward. Other motors are of the synchronous type running at a constant speed and are used for operating clocks, timers, such as controlling frequency of defrost and other purposes.

Control motors may be designed to operate at a given speed from a full open position to a full closed position in a certain length of time. This type of motor can be used for operating a valve controlling a liquid flow. The gradual acting of the valve, both opening and closing prevents liquid hammer or other shock to the piping system that can be generated if a fast acting solenoid valve is used. Other motors are designed to modulate a flow of fluid, liquid or air, to obtain a desired flow and will open or close partially on demand from a governing control such as a thermostat. This type of control allows partial movement of a control to meet the demands of temperature or pressure or other faction being controlled.

Practically all control motors operate on single phase current with low voltage normally being favored, particularly on modulating controls. Thermostats, pressure switches and other means of actuating control motors are designed with off-on circuiting or bridge circuited for modulation between on and off. Solid state controls may also be used as an actuating means.

Single Phase Motors–Power

Single phase motors will usually be found in the smaller sizes up to 3/4 or 1 hp with voltage ratings of 115 or 230 volts or with reconnectible windings for either voltage. Speed range usually will be found from 1150 rpm to 3500 rpm with probably the majority operating at 1750 rpm. Some small evaporators may use a very small motor, as small as 1/20 hp, and these very small motors may operate at speeds as low as 1050 rpm. Most single phase motors in warehouse use will range upward from 1/4 hp to 1 hp with some overlapping at the higher end with three phase motors. Single phase motors are used in the brackets mentioned above because they are manufactured in large quantities for a great many uses and are easily obtainable for replacement from multiple sources. Three phase motors in this range, on the other hand, are sometimes difficult to find. The small single phase motor is therefore used mostly as a matter of convenience rather than any actual superiority over the three phase motors. In measuring single-phase ac power, power factor must be considered.

In measuring dc power, the power used is determined by multiplying the amperes by the volts. This same procedure would be correct for single-phase alternating current, but the voltmeter and ammeter do not always indicate the true effective volts and amperes. This is caused by the inductive and the capacitive effect in an ac system. The power formula for a single-phase ac system will, therefore, be

E (volts) × I (amperes) × pf (power factor as a decimal) = Power (watts)

Power Factor and Load Factor

Engineers often confuse the term power factor with load factor and use them indiscriminately. The value of the power factor may vary from 40% or 0.40 under very bad conditions to near 100% or 1.00 under more ideal operating conditions. The low power factor does not indicate that the efficiency is appreciably lower than that at higher power factor. The actual power purchased is based on the true kilowatts. But low power factor does introduce a bad operating condition by excessive heating and should be corrected if possible.

Load factor, as usually computed, is a ratio of the average kilowatts used over a stated period of time to the maximum demand as based on a maximum-demand meter reading. The period of time on which this maximum is based is important. A period so short as when an unusual rush of current caused by some very temporary disarrangement becomes the basis of computation would be manifestly unfair. Such a maximum is generally based on an average of the three highest loads maintained over a 5-, 10- or 15-min period during the month.

Power Factor Correction

Almost without exception, any plant utilizing electrical apparatus will operate at a power factor less than unity. Incandescent lights operate at unity power factor, fluorescent and power lighting will average about 90% power factor. Large electric motors will operate at power factors of 80 to 90% while small fractional hp motors may operate as low as 50% power factor.

Low power factor means that extra circulating currents will be found in the distribution system. Actual kilowatts consumed are no greater in low power factor apparatus; but the additional current (often called wattless current) does increase line heating losses with a consequent increase in power consumed. In severe cases, the additional circulating can cause a total current draw high enough to cause some remote voltages to be below the acceptable limit and thus requiring new electrical mains.

Correction of power factor is possible and practical. It is usually done by placing capacitors across the phases. The increased capacitance will offset the reactance set up by rotating electrical machinery so that a plant may operate at an improved power factor. This improvement may be taken to any point desired. Capacitors may be placed at a panel to correct a number of motors or as a complete system correction. Each distribution system will need a study to determine the best correction for a particular plant. Larger capacitors are not necessarily cheaper to use on a complete system than individual smaller capacitors at each motor, particularly if the smaller one falls in the classification of a mass produced capacitor.

Plant correction of power factor is important and should be analyzed from time to time to determine if it is within best operating limits. Cold storage plants employing a great number of small horsepower motors as fan motors on evaporators are particularly vulnerable to low power factor operation if not corrected.

Use of Single Phase Motors

Small single phase motors have many uses in a cold storage plant. They are probably used most often to direct drive evaporator fans in both coolers and freezers. Standard motors can be used although special attention is sometimes needed in freezer rooms to insure proper lubrication for cold conditions. Small pumps, power tools as well as very small compressors are often driven with single phase motors.

Types of Single Phase Motors

Single phase motors, in order to be self starting normally use some type of means to throw one winding out of phase with the main winding to produce a starting torque for the motor. Once the motor is up to speed, the extra means of starting may be cut out of the circuit since the motor will continue to run without this assist. Single phase motors are usually classified by the means of starting such as capacitor start in which a capacitor is introduced into the starting winding to increase the torque in starting. The capacitor start motor has a relatively high starting torque and can be used for driving small compressors and other equipment requiring high starting torques. The repulsion-induction motor also has a considerable amount of starting torque and is frequently used for fan and pump drives. In smaller sizes, the shaded pole type motor can be used for low starting torque loads such as propeller fans. Both the capacitor type and the repulsion-induction motor have a mechanism that will remove the starting means, usually a centrifugal switch or a brush lifting mechanism to disconnect the starting means. The shaded pole motor is limited in its size and does not require a disconnect means.

Three Phase Motors

In warehouse practices there is no hard and fast rule but usually motors larger than 1 hp in size will utilize three phase current. The motor itself is of simpler construction than the single phase, starting is less complicated and efficiency and performance of the three phase motor is usually superior to the single phase. Three phase motors are used for a great variety of purposes. The most common speeds are approximately 1150 rpm, 1750 rpm and 3500 rpm for induction motors. Synchronous motors run at a synchronous speed somewhat above the induction speed which has some slip under synchronous speed. Synchronous speeds corresponding to the above three speeds are 1200, 1800 and 3600 rpm. The speed of a motor is determined by the number of poles in the electrical circuit with two poles being the least possible and producing a synchronous speed of 3600 rpm which is the highest speed attainable in a standard induction motor operating on 60 hertz power. Four poles produce a synchronous speed of 1800 rpm and six poles 1200 rpm, etc. The higher speed motors require somewhat less material and can be of a lighter construction.

The fundamental three-phase power equation is

$$E \times I \times pf \times 1.73 = P \text{ (in watts)}$$

The value of E (volts) and I (amperes) may be taken as the reading on any one phase on the assumption that the load is balanced on all phases. The constant 1.73 is derived from the square root of 3, this being the mathematical relation between phases. Power factor (pf) can usually be obtained from the motor manufacturer.

Types of Three Phase Motors

There are numerous types of motors and enclosures for electric motors a few of which are germane to the cold storage industry and which are enumerated below.

(a) The squirrel cage induction motor is probably the most widely used motor and is used for compressor drives, fan drives, pumps and numerous other uses. It can be built for high torque across the line starting, reduced voltage starting or part winding starting. A considerable variety of speeds are available, the most common synchronous speeds for induction motors being 1200, 1800 and 3600 rpm. Actual motor speeds, due to slippage in an induction motor, will be slightly below the synchronous speed. Direct drives can be of almost any size with belted drives limited somewhat to more moderate speeds, 1800 rpm and below, and about 100 hp unless special bearings are used against the pull of the belts. Direct drives eliminate belt losses and maintenance and are often favored where constant speed is desired. Speeds of belt drives can be altered by changing pulleys and is a desirable feature in some instances. Three phase motors are most common above 1 hp in size although smaller sizes are produced but not too often stocked.

(b) Wound rotor induction motors have a winding in the rotor or rotating part of the motor. In a standard induction motor, the rotor has no windings but only stationary bars forming a flux path. The wound rotor is connected to a controller external to the motor by wiring and collector brushes to the rotor. Varying the electrical resistance in the induced rotor current can produce a variable speed. Many of these motors have been used as a means of varying capacity by speed variation. However, controls and motors are relatively expensive and this type is not in as general a use as it formerly was in warehouse operations.

(c) Synchronous motors were used rather extensively in slow speed applications for direct drive of reciprocating compressors. Speeds of 300 to 400 rpm were quite common. The rotor of the synchronous motor was used as a flywheel of the compressor. These motors were relatively expensive but formed a very good means of driving older type reciprocating compressors. As the older, slow speed compressors were replaced by higher speed ones, the synchronous drive compressor fell into disuse. There are a number operating today but very few new installations are being made.

Motor Starters

Electric motors are started by applying current to the motor. The across-the-line type starter which is essentially an electrically operated switch which switches current to the motor windings on demand of some control, is the simplest form of starter and is used extensively, particularly on smaller motors. Since motors draw a considerable surge of current on starting, the size motor to be started across the line may be limited by the ability of the network serving a plant to provide this heavier current for starting purposes. Where full starting current is impossible, various forms of limiting starting current may be employed. Reduced voltage starting also reduces starting current and motor starting torque and is obtained by transformers in the starter. It is also produced by reconnecting windings in the motor itself to ease the starting current. Any of the reduced voltage starters are effective but somewhat complicated compared to the across-the-line starter and are more expensive. Switching is also more complicated.

Motor protection is quite often built into the starter by means of heater relays which will interrupt the starting and running control to the motor starter when current draw becomes too heavy for the size motor. In smaller motors and particularly single phase motors, protection is built into the motor itself by means of temperature sensors in the motor windings which open if the temperature exceeds limits.

Motor starters are an important part of any plant utilizing electric motors. Automatic starters are common and reliable when used properly and are a valuable part of the control system in an automatic plant.

Classification of Electric Motors

The National Electrical Manufacturers Association (NEMA), supported by the manufacturers of electrical apparatus, classifies motors by size, application, electrical types, method of cooling and mechanical protection as well as mounting configuration. Various manufacturers of electrical motors classify their motors to the NEMA standards.

Cold Storage Power

Prior to World War I, most cold storage plants were powered by steam engines. There were 2 reasons for this: (1) fully 70% of cold storage warehouses were associated with ice plants and a major portion of ice plants were dependent upon steam condensate for their "so-called" distilled water for clear ice; (2) condensing steam turbines that might well supply ample condensate for the ice-making function were not adapted to operating at the low speeds essential to driving refrigerant compressors. Even if condensing turbines might be geared down to drive refrigerant compressors, equipment of this type was not available on the American market before 1925.

From 1885 to 1915, most large refrigerant compressors were driven by horizontal compound Corliss engines. The compressors were of the slow speed, long stroke, small bore design often of the jack knife type; that is, the steam engine was horizontal, the compressor vertical, primarily to economize on floor space.

In another application, a large, slow-speed horizontal ammonia cylinder was placed alongside the steam engine cylinder. A large flywheel between the cylinders was driven by the steam engine and connected through a cross head and rod to the refrigerant cylinder. These refrigerant compressors were relatively efficient in operation and compared favorably, and, in many instances, were of a higher efficiency than many of the modern compressors. They were extremely heavy and space consuming and if manufactured today would be almost prohibitively expensive to manufacture since industry is not now geared particularly for this type of machine. Space costs also would enter into the use of such machinery.

Steam engines of the old compressor drive type have not been manufactured for a number of years for this purpose and this era of refrigeration drive is almost a thing of the past.

The change over to electric or diesel engine drive of the compressor came between 1920 and 1935. This was brought about by: (a) change over from distilled to raw water for ice making; (b) adoption of high speed short stroke refrigerant compressors for both ice making and cold storage; and (c) more attractive power rates for purchasers who would use synchronous motor drives for all applications requiring an electrically driven compressor of 50 hp or more. Such a synchronous motor was most helpful to the power company in establishing a better power factor in the region of the ice plant or warehouse.

Internal Combustion Engine Drives for Refrigeration Plants

For cold storage, ice production, locker storage and general refrigeration plants the Otto and Diesel cycle oil engines are most serviceable as a standby unit. In some of the smaller cities that are removed from the large electrical distribution systems, and even in some cities where electrical power is available but is sold at prohibitive rates, either the Otto or Diesel engine may be found to be most economical as the principal engine and as well for standby service.

In accepting the responsibility for providing uniform low temperature for the storage of perishable products, one of the first requirements for a successful storage plant is dependable power. Where this cannot be guaranteed by the electrical suppliers, it is recommended that a stand-by emergency power supply be furnished by either Diesel or other engine power. If the electrical power is not dependable, it is advisable to install both the principal power source and the stand-by or Diesel or other engine power.

For the smaller installations such as locker plants, the gasoline engine or natural gas engine with full automatic controls is most desirable. Diesel engines are not generally available in capacities below 30 hp.

Classification of Internal Combustion Engines.—Internal combustion engines may be classified by several methods. Classification may be by the fuel burned, such as kerosene, butane, gasoline, gas or oil; by cylinder arrangement, as horizontal, radial, vertical, opposed, etc; by type of cycle, such as Otto, Diesel, etc; by the number of cylinders, as single cylinder, multi-cylinder; and by application, such as tractor, automobile, airplane, marine, stationary, etc.

The internal combustion engine may be of low, medium or high pressure. The low-pressure engines are those that generally do not exceed compressions of 150 lb and an explosion pressure of 250 lb. The injected fuel is sprayed on to a hot bulb or a hot plate where it is heated and vaporized; with the heat of compression ignites the fuel-air mixture and performs the work of the engine power stroke.

The medium-pressure engines develop a compression pressure of 250 to 350 psi; then the fuel is injected at the end of the power stroke. The explosion will raise the pressure to 400 to 500 psi.

The high-pressure, more commonly called Diesel engine, may be either 4-stroke or a 2-stroke cycle engine. The charge of air is compressed in the cylinder to approximately 500 psi which results in a temperature of probably 1,000°F. At the end of this stroke the fuel oil is fed into this hot compressed air by a high-pressure pump, and a slow ignition results.

Internal combustion engine use has probably dropped by a considerable amount in recent years. Good maintenance mechanics are becoming few and far between. Plant automation is difficult with internal combustion engine drives. Uncertainty of fuel availability is also an increasing problem. All of these factors tend to point to electric motor drive for cold storage operation as desirable for most sites and designs. Internal combustion engines can be economical in fuel consumption but first costs and the above factors seem to rule them out in most instances.

TURBINES

By definition the turbine is a machine for generating mechanical power in rotary motion from the energy in a stream of fluid. The energy in the fluid, originally in the form of head or pressure energy, is converted to velocity energy in passing through a system of stationary and moving blades in the turbine. Changes in the magnitude and direction of the fluid velocity are made to cause tangential forces on the rotor blades, thus producing power as the rotor turns. The most commonly used fluids for turbines are steam, hot air or gaseous products of combustion, and water. Turbines drive about 95% of all electrical power producing generators in the world, and are used for innumerable other mechanical drives.

Steam Turbines

Steam turbines came into use in North America about 1910. For most refrigerant compressors of that date the speed of steam turbines was too high for practical application to the existing low speed refrigerant compressors. When steam turbines were used for power for cold and freezer storage energy, whether privately financed or through a public utility, the turbine was directly connected to an electric generator and the power at the refrigerant compressor was supplied through an electric motor.

Steam Turbine Classification

When classified according to method of steam expansion a turbine is specified as (a) impulse, or (b) reaction. In the impulse turbine the fluid is accelerated through the stationary blades and then made to impinge upon the rotor blades or buckets, thus having its direction changed and producing a force on the rotor with substantially no pressure change while passing through the rotor.

Impulse Turbine.—In an impulse turbine the expansion occurs in the stationary blades or nozzles only. By this expansion the steam gains high velocity and impinges against the blades or buckets and drives them forward, causing the rotor to revolve.

Reaction Turbines.—In the reaction turbine the expansion of the steam occurs in the rotating blades or buckets. The reacting force of this steam gaining velocity in the blading is similar to that experienced when trying to hold a fire hose under high pressure. The hose reacts or swings back with great force.

Steam Turbine Classification by Stages of Expansion

When classified according to stages, steam turbines are made up as (a) single stage, and (b) multi-stage.

The multi-stage turbine gives the same horsepower at a slower speed than the single-stage turbine for the same amount of steam used. Multistaging is, then, the designer's method of getting slower speeds on turbines.

Gas Turbines

Gas turbines came into commercial use as a power source after World War II. They are available for many applications in gas turbine electric generator sets and for aero, marine and automobile power units.

Gas Turbine Arrangements

Gas turbines can be constructed for single or multiple-shaft arrangements. They can be arranged to supply power, high-pressure air, or hot-exhaust gases either single or in combination.

A single-shaft unit, consisting of a compressor, combustor and turbine, is a compact lightweight power plant. It is capable of rapid starting and loading and has no standby losses. It can be arranged to use little or no cooling water, which makes it particularly attractive for powering transportation equipment and as a mobile standby and emergency power plant. This type of plant can compete efficiently with small steam plants. Its simplicity involves a minimum of station operating personnel; some of these plants are arranged for completely remote operation.

To improve efficiency, the energy in the exhaust gases can be used either in a waste-heat boiler, or combination with other processes. For example, a unit arranged to supply process air at 35 psig for operation of blast furnace can use blast-furnace gas for its fuel.

The turbine material above is given more as a matter of information than as expected use in a cold storage plant. For efficient use of turbines, large horsepower usage must be considered which are normally above any cold storage plant requirements except an extremely large installation and even then the contemplation of a turbine generator installation should be closely studied from all angles. Turbine plant operators and refrigeration plant operators are not usually found in the same person which leads to a dual operation when turbines are considered.

FOUNDATIONS

Foundations for rotating machinery, such as refrigeration compressors can take many forms and sizes. In the early days of refrigeration machinery, slow speed heavy duty compressors were built without too much thought as to complete balancing of rotating parts. To offset this imbalance large heavy concrete foundations were used to anchor the compressors completely to a large mass of foundation material usually poured in direct contact with the ground. Later designs utilized heavy springs and other vibration absorbing materials under a moderately heavy foundation block.

Many of the modern higher speed compressors now require a minimum sized foundation block which can be poured in a pit or anchored to a floor. Balancing has improved on the rotating compressors to a considerable degree and the extremely heavy foundations formerly used are not usually found in todays plant design.

It is always well to follow the manufacturers recommendations on foundations required for any machinery. The good design engineer will incorporate these recommendations into the overall plant design to achieve good results. Foundations are important to the operation of any machinery and should be given careful consideration in the design of any plant.

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19

The Rise and Expansion of the Refrigerated Food Industry

INTRODUCTION—ORIGIN OF MEAT, FISH AND POULTRY FREEZING

Freezing has long been recognized as an excellent method of food preservation. Since early times, farmers, fishermen and trappers residing in regions having long cold winters have prepared their fish, game and other meat by freezing and storage in unheated buildings.

The freezing of beef and mutton was practiced in Midwestern United States and Canada even before these areas were divided into states and provinces. Farmers and ranchmen utilized snow and pond ice to pack their early winter killings of cattle and sheep for family and community use. These killings were timed to fit the advent of wintry or freezing weather and significant snowfall. These would reduce the hazard of meat spoilage before the proverbial late February thaw of some months later. To provide the home-killed meat needs for the year without requiring butcher shop purchasing, it was traditional to name the first frosty nights of fall "hog-killing weather." Thousands of hogs were slaughtered by individual families during this early fall chilly period. The most perishable parts of each hog, such as the heart, kidneys and liver were packed in pond or commercial ice and eaten as fresh. The other less perishable portions were converted into spiced and seasoned sausages and the rear and front quarters salted or smoked. Finally the side meat was rendered and leaner sections sliced and placed in jars of well-salted melted lard. These pork products provided probably 90% of the family summer meat consumption for the producing farm families, the other

10%, usually beef, mutton or fowl, being supplied on special days from their poultry flocks or from the butcher shop.

Actually frozen beef and mutton were accepted as most satisfactory meat provisioning by North American farm families many decades before frozen steaks and lamb chops were "tolerated" by the city gentry. Economic necessity of the farm and ranch meat producers of North America made frozen beef and mutton an acceptable table meat provision for many years before the more sophisticated tables of North American and Western Europe would admit that they could possess high quality and be delectable.

Australian and New Zealand Frozen Meat

The first successful shipment of frozen beef was transported by D. Peyton Howard from Indianola, Texas, to New Orleans, Louisiana, in 1867 and served in hospitals, hotels and restaurants. Simultaneously, Thaddeus S. C. Lowe equipped a vessel with commercial dry ice under British patent and transported frozen meat from New York to Louisiana.

The first successful shipment of frozen beef across the equator was carried on the steamship Paraguay from Buenos Aires to Marseille via Havre in 1877. This was followed by a successful shipment of frozen meat from Australia and New Zealand to the Smithfield Market, London. It originated at Melbourne, November 29, 1879 and arrived in London in excellent order, February 2, 1880.

By 1881, other steamships were equipped for freezer refrigeration of meat. The Dunedin sailed from New Zealand with 9,000 frozen carcasses of mutton and lamb and some butter for London. On arrival the product was advertised and sold as good and prime quality.

Advent of Quick Freezing

The advent of quick freezing revolutionized food freezing. The demand for frozen meats, poultry, eggs, fruits and vegetables gave new life to the industry. However, according to Enochian (1968), growth of the frozen fresh food industry was slow in its early years. Economic factors, such as the Great Depression of the 1930's, no doubt contributed to this slow takeoff. The time lag required to build up storage and distribution facilities and the lack of venture capital for investing in an industry whose future was still uncertain, also had a delaying influence on industry growth.

Consumer prejudices and long established habits had to be overcome, or had to await the fresh outlook of a new generation of Americans, before the industry could achieve a rapid rate of growth.

During the past 40 yr, frozen foods made tremendous gains due to the pioneering and continuing research by frozen food processors, container manufacturers, the state colleges, and state and federal government agencies. This research has been concerned with improvements in the freezing process itself, and improvements in the product through breeding of better strains, better selection, preparation, and handling of raw product. Equal attention is being given to preservation of product quality during marketing. An important part of the research has focused on developing information on the effects of time and temperature on frozen food quality during transportation, storage, and merchandising. As this information was translated into government and industry standards for maintaining good quality throughout the entire marketing process, as advertising and promotion attracted consumers, and as investments were made in facilities for handling frozen foods, the industry grew rapidly.

According to Anderson (1953), production of all frozen foods combined rose from 568 million pounds in 1941 to 1,028 million pounds in 1945, and then in 1946, it rose to 1,317 million pounds. The requirements of the armed services, shortages of the war and postwar periods, and derationing of frozen fruits and vegetables seven months sooner than canned goods, all contributed to the rapid expansion. In 1947, the boom came to an abrupt halt. Overproduction resulted in large inventories of frozen foods, some so poor in quality as to be inedible. Demand fell off, partly because of the restoration of normal conditions and partly because of the injury done consumer acceptance by the presence of inferior products on the market. In the squeeze of 1947, many processors were forced out of business, as were most of the specialized frozen food stores and home-delivery services that had mushroomed after the war. The effect of those conditions on 1947 production is shown in Fig. 17.1. The setback was only temporary, for in the next year sales revived, and in 1949 production reached a new high.

Since 1949, production of frozen foods has grown steadily, reaching an all time high of nearly 13 billion pounds in 1962. This included 5.1 billion pounds of frozen fruit juices (reconstituted basis), most of which was concentrated orange juice which also reached an all time high that year. This surge in orange juice production was due to the exceptionally large crop of oranges in Florida that year. In 1963, the production of frozen foods fell below the level that had been achieved 5 yr earlier primarily because of the much smaller production of concentrated orange juice which was a result of a small orange crop that year. Since 1963 (Enochian 1968), there has been a resumption in the steady rise in total production of frozen food.

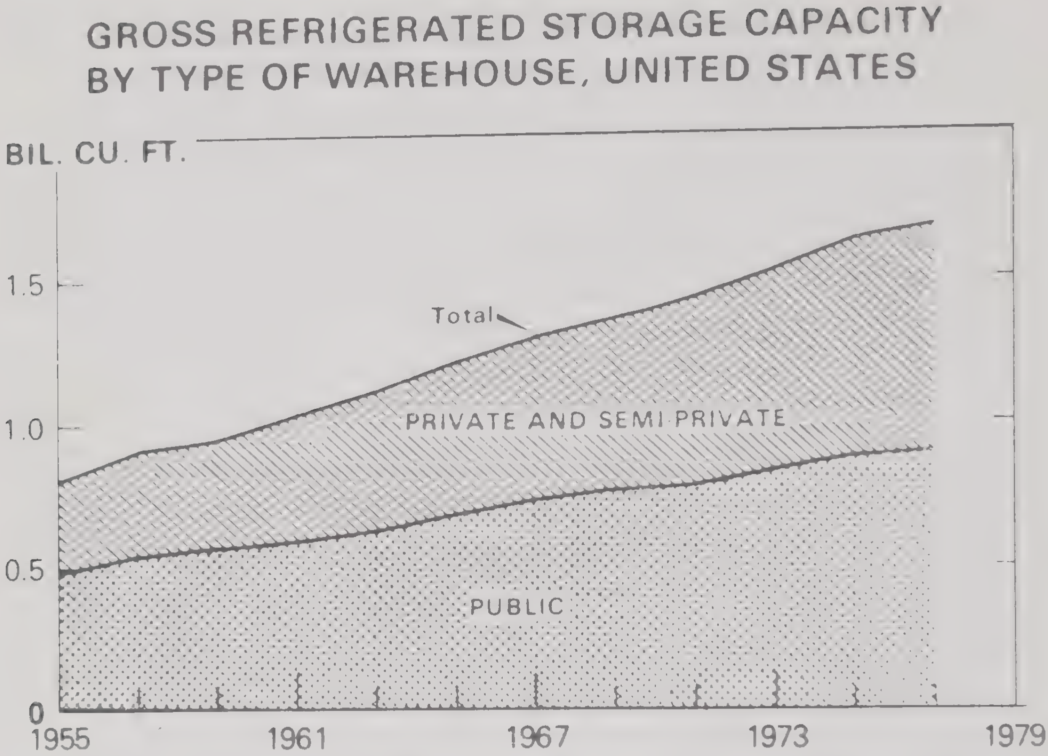

FIG. 19.1. GROWTH IN U.S. FROZEN FOOD PRODUCTION 1945–1965.

THE ADVENT OF FROZEN PRECOOKED FOODS

Although the Birdseye Laboratories in 1932 tried to market pilot packs of a few frozen precooked foods (squash, corn on the cob, and lobster), it was not until near the end of World War II that a large line of these foods was packed. Since the end of that war, a very great number of frozen precooked entrees, vegetables, baked goods, desserts, meals on a tray (TV dinners), etc. have been offered. The quantity of the frozen French fried potatoes produced is greater than that of any other product. Many other precooked foods are frozen on a large scale. Frozen precooked foods have been generally accepted by modern homemakers as the best of convenience foods. The increase of production of these products is continuing steadily and is likely to continue.

Cost of Freezing

Contrary to what most persons believe, the freezing of foods is not a costly operation. In general, the cost of preparing fruits and vegetables for freezing is the same as the cost of preparing them for canning. There is not much difference in the cost of containers used for frozen foods and those for canned foods. In fact, in many instances the cost of containers for frozen foods is slightly less per pound of food packed. This is particularly true of the large containers used for products packed for the institutional and wholesale trade.

The relative costs of freezing and processing (pressure cooking) operations will depend upon three principal factors: (1) the length and severity of the process (cook) required to sterilize the product; (2) the cost of fuel for generating steam and the price of electricity; (3) the amount of labor involved in handling the products during freezing or processing. Certain fruits, e.g., grapefruit, and fruit juices, that may be sterilized by passing the can through a hot water bath or by flash pasteurization, may be processed for less than they can be frozen. On the other hand, unless the cost of steam is very low indeed, vegetables which require a long process (cook) may be frozen more cheaply than they can be processed. With the exception of locker plants and small freezers, the vast majority of the commercial freezing plants use ammonia machines. While there are slight differences in the efficiency of the various ammonia refrigeration machines, the difference in the cost of liquefying ammonia is not very great.

Vegetables contain, on the average, 90% water and fruits about 85%. It is evident that about the same amount of refrigeration is required for freezing foods as for ice making, but at somewhat lower temperature. The cost of freezing is not excessive. In the face of ever increasing energy costs, freezing costs are also on the increase but are still reasonable.

FUTURE EXPANSION OF FROZEN FOODS FROM THE TROPICAL ZONES

With the increase of population to many nations of the world, the needed food supplies, especially of fish and fruit, may well be augmented from the tropical seas and regions of the verdant earth. The food shortages of the Western Europeans and the British in the nineteenth century were finally solved by the frozen food importations largely from South of the Equator to supplement the established imports from North America. The temperate regions of Australia, New Zealand, Argentina, Uruguay, Chile, Southern Brazil and South Africa supplied a large amount of the perishable foods most acceptable to Western Europe by steamship. Each steamship in its 4 to 6 weeks journey with frozen meats and butter in the refrigerated holds, passed over nature's storehouse of billions of tons of tropical fish, exotic fruits and nutritious nuts not yet acceptable to the northern food brokers, chefs, green grocers, fishmongers and butchers of Europe and Britain.

The expansion of use of frozen foods that can be anticipated from the tropical and semitropical zones will require an entirely new organization

TABLE 19.1. GROSS REFRIGERATED STORAGE CAPACITY, BY TYPE OF WAREHOUSE, UNITED STATES

Year	Public	Private and Semi Private	Total
		Mil Cu Ft	
1955	499	314	813
1957	545	356	901
1959	567	375	942
1961	595	432	1,027
1963	633	479	1,112
1965	684	519	1,203
1967	735	559	1,294
1969	762	591	1,353
1971	774	653	1,427
1973	829	686	1,515
1975	876	755	1,631
1977	894	785	1,679

Capacity of refrigerated whses., March 1978 5 Crop Reporting Board, ESCS, USDA.

TABLE 19.2. VEGETABLES FROZEN—U.S. COMMERCIAL PACK INCLUDES POTATOES (FIGURES IN MILLIONS OF POUNDS)

1967	3508
1968	3858
1969	3915
1970	4317
1971	4574
1972	4875
1973	5158
1974	5473
1975	5213
1976	5491

Figures from USDA—Economic Research Service.

of food suppliers to gather, freeze, transport under refrigeration, and market some of these billions of tons of fish from the equatorial seas, and nuts and fruits from the regions between 30° North and 30° South latitudes. Coincidentally, the natives of these same zones will learn the wisdom of conserving by freezing to prevent decaying and then marketing the surplus they now discard as inedible. This tradition in harvesting, transporting and marketing techniques of tropical perishable foods together with the expanding use of already established sources of frozen foods by those of lower income levels cannot be accurately predicted. Since all-round quality of most frozen foods, especially in flavor, color, texture and vitamin content, is superior to that of the canned product, it is only logical to assume that freezing will eventually become the most important method of food preservation in these areas.

TABLE 19.3. FROZEN VEGETABLES PER CAPITA CONSUMPTION IN POUNDS

Ave.-1947–48	2.86
Ave.-1957–59	8.13
1965	13.80
1966	15.76
1967	16.64
1968	18.16
1969	18.94
1970	20.75
1971	21.84
1972	22.22
1973	23.96
1974	23.41
1975	23.54
1976*	24.99

* Preliminary USDA.

TABLE 19.4. STOCKS IN STORAGE

Commodity	Dec 31, 1977	Dec 31, 1978	Dec 31, 1979	1979 As Percent of	
				1977	1978
		1,000 pounds		percent	
Butter	184,907	206,930	175,548	95	85
Cheese, total natural	468,629	436,372	507,855	108	116
Eggs, frozen	29,664	25,296	23,527	79	93
Fruits, frozen	607,841	517,943	557,184	92	108
Fruit Juices, frozen	613,021	714,031	733,057	120	103
Meats, total red	566,638	723,558	710,659	125	98
Beef, total frozen	315,555	405,351	353,922	112	87
Pork, total frozen	185,854	241,806	282,851	152	117
Poultry, total frozen	310,038	280,138	386,234	125	138
Turkeys	167,943	175,097	239,157	142	137
Vegetables, total frozen	1,645,470	1,800,533	1,872,867	114	104
Potatoes, total frozen	829,769	777,473	811,544	98	104

Data for this report are collected from public and private refrigerated warehouses storing commodities for 30 days or more Stocks in space owned or leased by the Armed Forces are excluded Food stocks held under bond are included in the storage data. USDA Crop Reporting Board Economics Statistics and Cooperatives Service.

TABLE 19.5. REFRIGERATED SPACE BY TYPE OF WAREHOUSE, UNITED STATES, OCTOBER 1, 1977

Type of Refrigerated Warehouse[1]	Storages	Gross Space			Usable Space		
		Cooler	Freezer	Total	Cooler	Freezer	Total
				1,000 cu. ft.			
General Storages:							
Public	672	179,530	681,012	860,542	133,909	504,307	638,216
Private and Semiprivate	818	156,352	281,758	438,110	110,989	206,988	317,977
Apple Storages:							
Public	49	32,636	411	33,047	26,497	317	26,814
Private and Semiprivate	1,622	340,598	6,235	346,833	269,666	4,793	274,459
Total	3,161	709,116	969,416	1,678,532	541,061	716,405	1,257,466

TABLE 19.6. GROSS REFRIGERATED SPACE BY TYPE OF WAREHOUSE, UNITED STATES, OCTOBER 1, 1961–77

Type of Refrigerated Warehouse	1961	1963	1965	1967	1969	1971	1973	1975[2]	1977
					1,000 cu. ft.				
General Storages:									
Public	555,598	598,978	648,500	701,110	730,127	740,391	798,838	844,946	860,542
Private and Semiprivate	246,026	269,687	300,925	318,580	331,804	375,767	398,217	419,828	438,110
Apple Storages:									
Public	39,865	34,469	35,472	33,694	32,076	33,872	29,853	30,346	33,047
Private and Semiprivate	185,314	208,935	218,493	240,721	258,739	276,947	288,260	334,944	346,833
Total	1,026,803	1,112,069	1,203,390	1,294,105	1,352,746	1,426,977	1,515,168	1,630,064	1,678,532

[2] Revised. Crop Reporting Board, ESCS, USDA.

TABLE 19.7. STOCKS IN STORAGE

Commodity	Jan 31, 1978	Jan 31, 1979	Jan 31, 1980	1980 As Percent of 1978	1980 As Percent of 1979
		1,000 pounds		percent	
Butter	195,713	206,653	190,001	97	92
Cheese, total natural	459,564	436,638	514,826	112	118
Eggs, frozen	27,043	25,477	21,531	80	85
Fruits, frozen	549,399	497,977	514,808	94	103
Fruit Juices, frozen	735,511	1,000,115	1,016,779	138	102
Meats, total red	559,106	728,359	736,000	132	101
Beef, total frozen	314,021	423,712	369,661	118	87
Pork, total frozen	174,003	224,497	286,125	164	127
Poultry, total frozen	304,559	279,803	388,932	128	139
Turkeys	168,266	170,674	249,145	148	146
Vegetables, total frozen	1,471,485	1,580,935	1,650,498	112	104
Potatoes, total frozen	862,559	778,695	832,269	96	107

Data for this report are collected from public and private refrigerated warehouses storing commodities for 30 days or more. Stocks in space owned or leased by the Armed Forces are excluded. Food stocks held under bond are included in the storage data. Crop Reporting Board ESCS, USDA.

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Meat Poultry and Fish Cold Storage and Freezer Storage Rooms

The usual public cold storage warehouse does not, as a rule, contain cooler space devoted to meats, poultry or fish since cooler storage life of these products is of short duration and does not lend itself well to public warehousing. Quite often, however, space in public warehouses may be leased to individuals or companies for their various uses in processing and handling such products. Cooler space is most frequently leased although freezer space may be required in some instances.

MEAT STORAGE

The fresh meat processor usually requires a meat storage room (cooler) with meat rails for hanging carcass meat and a processing room for cutting and processing meat products. Processing equipment is normally furnished by the lessee. The storage and process rooms are sometimes combined into a single area or may be separate rooms depending on the size of the operation and the type of processing setup desired and on local requirements. Several small processors are sometimes accommodated in a single large room partitioned into small areas and each area leased to a different meat processor. Areas may range from a few hundred to several thousand square feet.

When remodeling or building new rooms for lease to any meat processor, local and federal regulations applicable to such areas should be carefully checked with regard to room requirements. These regulations will be found to be strict in the matter of sanitation and other related requirements. Extra drains and sewer lines are often necessary as well as provision for an abundant supply of hot water. Special wall and floor finishes may also be found to be necessary to comply with various codes. Much trouble can be avoided if the proper authorities are consulted regarding applicable regulations before a space is converted or constructed for processing.

Design Items

A typical operation will require a meat storage room with meat rails for hanging meat to be processed. A single rail will usually extend out of the room through a track door and across the loading dock for the receiving of meat from incoming transportation. When extending the rail over the dock area, it is necessary to provide a hinged section or some device for raising the rail so that normal dock traffic may proceed when the rail is not in use. The meat storage rail system within the room should be arranged to suit the requirements of the tenant to give him adequate length to store his anticipated storage load. In addition to the rails, there may be shelving for the storage of processed meat and clear storage space for pallets or push trucks as required. Processing of the meat will usually take place adjacent to the storage area, sometimes in a separate room and sometimes in a low partitioned space taken from the storage space. The processing area will contain the processing equipment required for the particular operation such as saws, grinders and other equipment. Ample electric power is necessary in the processing area to supply adequately all of the processing equipment. In larger operations, an office will be required. This can be set up inside the cooler if no other space is available. These offices are usually small. When set up in a cooler area, they should be well insulated and heated. Electric heat will be found to be the most practical method of heating in most instances.

Special Items of Consideration

Small processors will usually require a much simpler type of space usually consisting of a single room at cooler temperature in which processing is done on quarters which are hand trucked into the room. Shelving may be constructed in the room to hold completed orders. Processing equipment is installed to meet the requirements of the individual operator. As regulations become more strict, the number of small processors tend to become fewer and the larger operations will be found to dominate.

Refrigeration for processing and meat storage rooms sometimes utilizes the existing compressors and system. The cooler facilities of the refrigerated area are converted for meat storage using the installed refrigeration. At other times, refrigeration is installed specifically for the meat processor. These load requirements are not heavy, as a rule, since the meat to be processed is usually received chilled. High humidity is desirable to prevent excess "shrink" of the stored meats and a temperature close to 32°F is required. In an existing installation, the high humidity desired sometimes requires the addition of more evaporator surface with proper controls to bring the humidity to a higher point than is normally carried in a standard cooler. This also limits the use of the remaining space in a cooler, if it is not all used for processing and storage, to cooler products that are not adversely affected by the high humidity. Blower coil units will usually be found in this type of room although brine spray units may be used occasionally. Some type of defrost, usually automatic, is necessary since these rooms are carried near the freezing point.

Cooking Facilities.—Special care should be exercised with any processor utilizing any cooking processes. Cooling requirements of meat products from elevated temperatures to complete cooling of the product are stringent and have been tightened considerably in the recent past. This usually requires additional refrigeration of relatively high capacity and should be taken in to account in any lease agreement.

In the processing room will be found various electric saws, grinders and other machinery required in the processing of meat from the carcass to individual steaks, chops, roasts, etc. Also required is a source of hot water in quantity and sometimes steam may be required for processing and cleanup purposes. This room will also be cooled although temperatures are not as critical as in the storage room area. In some instances this area will be cooled by the same refrigeration blowers used for the storage area and separated by a partial partition extending to about rail height. This usually occurs where the processing and storage room are part of an existing installation. Precautions should be taken to limit the load on the refrigeration units in the processing room during the clean up period. Hot water is used extensively for this clean up and a very high instant load can be developed in the refrigeration units which can cause trouble unless it is anticipated and proper precautions taken.

Retail Meat Refrigeration Storage.—Another type of meat operation is that of a wholesaler or processor storing processed meats only for distribution to retail outlets. This requires only a standard cooler storage space since meats of this type are usually well-packaged and do not require as careful control of humidity as carcass meat and exposed cuts. Quite often, a distributing setup will also require a small freezer for the storage of frozen products along with the cooler products stored in the cooler. A small freezer with automatic coil defrost is usually leased for this purpose. This freezer can be built inside of a regular large cooler room with a refrigeration coil of its own or can be a partitioned space in a larger warehouse freezer. Small unitized equipment can also be used for a remote freezer.

Leased space should be adjacent to or within easy access to dock space with adequate parking space for the lessees trucks and for loading and other requirements necessary to the operation. Many of the processors or wholesalers will use refrigerated trucks with stored refrigerant type plates. In the case of self contained condensing units to charge the plates, it will be necessary to have plug-in cords available so that the trucks may be refrigerating while at the dock. In the case of the eutectic cold plates with no truck condensing unit, connections to the warehouse refrigeration plant are necessary so that the cold plates may be charged while the truck is parked at the dock. This usually takes place over night.

POULTRY PRODUCTS

Poultry products are usually handled frozen in public warehousing. The freezing process is normally accomplished in the poultry processing plant and the finished product shipped to the warehouse for storage in a frozen state. In some instances, the product may be frozen in the public warehouse freezing facilities and stored. Very little if any cooler space is used in the public warehouse for poultry products.

SEAFOODS

Fish, and more especially shrimp, are held in coolers usually iced down in preparation for processing and freezing. Warehouses having shrimp freezing facilities will also have cooler space available to carry green shrimp until they can be processed. High humidities should prevail in the cooler areas and usually do without too much effort due to the fact that shrimp usually come into the room packed in ice. Other sea products may also be held in cooler storage preparatory to being frozen. This type of warehousing will most often be found in coastal cities, although some processing and freezing may be done inland during peak periods when coastal facilities are not sufficient to handle the load.

FREEZER STORAGE OF MEAT, POULTRY AND FISH

Meat, poultry and fish products, when frozen, can be held in general freezer storage at 0°F or lower. No special requirements must be observed since present day products are usually well-packaged for long freezer storage life.

Many warehouses have freezing facilities that can be used extensively for freezing meat products. Most meat products are not damaged by relatively slow freezing, and when carcass meat is frozen, no warehouse freezer temperature can effect quick freezing on account of the thickness of the carcass which prevents the rapid removal of heat. Many systems are used to freeze halves or quarters of beef. Often they are frozen in a freezer storage room equipped with some extra evaporator surface and auxiliary fans to insure good air circulation. The halves or quarters are hung on racks in the room and allowed to freeze over a period of time of 60 to 72 hr. Some specifications call for complete freezing of the carcass within 72 hr. This is not too difficult to accomplish in a standard freezer room with proper auxiliary fans and good air circulation. If much of this type of freezing is done, it is well to designate a freezer room for this with extra surface evaporator and additional air circulating fans. The room should not be used for storage since the additional air circulation required for freezing and also possible temperature fluctuations as loads are added tend to make an unsatisfactory storage room.

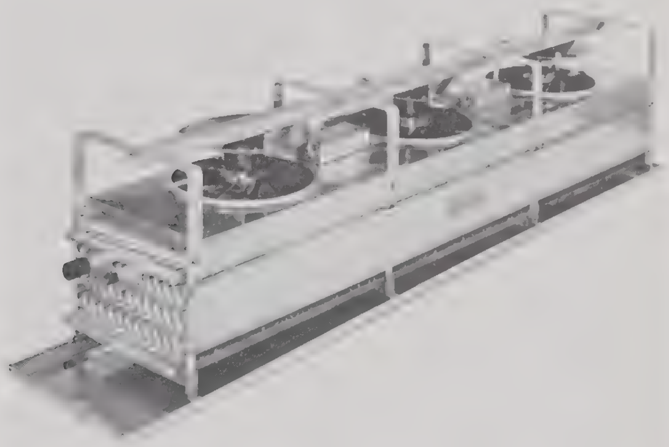

FIG. 20.1. MEAT COOLER UNIT ENGINEERED FOR HIGH HUMIDITY AND LOW AIR VELOCITY. MAY BE HUNG IN RAILED OR OPEN ROOM.

Courtesy of Krack Corp.

AIR BLAST FREEZERS FOR MEAT AND FISH

Plant blast freezers are often used for the freezing of poultry and fish products. In freezing poultry, and particularly turkeys, it is necessary to achieve a fairly rapid freeze. At least the surface of the bird must be quickly frozen to set the bloom or color which should be white or faintly pink. Extreme low temperatures are not essential to obtain this bloom but good air circulation is very necessary.

Freezing Shrimp

Shrimp freezing is a rather specialized operation and is usually handled by the shrimp packer. The warehouse usually leases him the space and quite often will sell the packer refrigeration in the form of metered refrigerant for use in the packer's own freezing equipment. Refrigeration is also sold on the basis of the tonnage of frozen product. The freezing may be done in plate type freezers, blast freezers or IQF freezers where the individual shrimp are placed on a conveyor belt and frozen by air blast. Most shrimp are packaged commercially in 5-lb boxes.

Glazing of Shrimp.—After freezing boxed shrimp, the box is opened by raising the lid and the contents glazed with a spray of water. This glazing effectively prevents dehydration of the shrimp and keeps them in good salable condition. When furnishing refrigeration for shrimp freezing and storage, consideration should always be given to the extra load imposed by the glazing process. The refrigeration required to freeze shrimp is greater per ton of product than for most products, due to the glazing process. The glazing is usually done after the shrimp are in storage. A pallet load or so is moved into a work space area, glazing them and then placing them back in the freezer. If this load is not taken into account and proper refrigeration added in the storage room to refreeze the portion melted by the water spray plus some thawing of the product while out of the freezer room, rather serious refrigeration shortage may develop with resultant erratic temperatures in the storage room.

Glazing of Hams.—Green hams intended for long time freezer storage are also glazed, at times, after freezing. This can be done individually by passing the frozen hams through a water bath and then piling them in the freezer storage room; or by direct water spray on a pile of hams in the freezer room. This glazing load is not as high as for shrimp since the amount of water frozen is not great compared to the total product weight.

If a warehouse is in an area containing several packing plants, it is possible that meat freezing can be an appreciable part of the load. An acceptable job of freezing on most meat products can be done in a standard freezer with extra cooling surface to accomodate the extra load imposed by the freezing. Temperatures are not too critical and good air circulation is more important than extreme low temperatures. If warehouse space is critical, meats can, of course, be frozen in a blast or tunnel freezer. Bear in mind however, that on carcass meats, no freezing process will allow quick freezing due to the thickness of the carcass. Good air circulation, again, is more essential than extreme low temperatures.

In drawing up a lease for the rental of cooler or freezer space, care should be exercised to spell out exactly what is to be furnished by both parties and also what alterations are to be made, if any, in the space to fit it for the use intended. As a rule, the lessee will furnish processing equipment such as saws, grinders etc. while the lessor will make alterations to the space and put in partitions, trackage, hot water supply and other like items. Alterations are usually figured at cost and this cost added to the price of the lease over the life of the lease.

A good lease must give the lessee what he needs for the satisfactory pursuit of his business, and at the same time, afford the lessor an adequate return on his investment and operating costs. If this is accomplished in the lease agreement, a mutually satisfactory relationship will usually follow.

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21

Commodity Storage Requirements

Cold storage warehouses, when serving the public, are usually equipped to serve as many types of storage as requirements dictate and as space can be profitably provided. Different parts of the country will require different types of storage and some commodities may be difficult to handle properly and be shunned by most warehouses thus leaving them for private or very specialized storage. The following pages of this chapter are intended to give a very brief look at a considerable number of commodities and their requirements for temperatures and humidities. Where a warehouse is seriously considering large scale storage of the commodities mentioned, detailed information can usually be obtained from government publications and existing texts and articles dealing with specific problems involved. It is recommended that considerable research be done to be certain that a particular warehouse can meet the requirements for storage and that the customer also understands fully the limitations, if any, of the warehouse facility concerning the product he wishes to store.

PEAR, APPLE, AND GRAPE STORAGE ROOMS

Season wise, especially in the river-plains north of the 40th parallel in the United States, varieties of apples may be classified under such names as: June, Summer, Fall, Snow and Winter apples. It is the latter varieties that the cold storage operator receives in vast tonnage for long term storage fruit. The important storage varieties are: Winesap, Rhode Island Greening, Baldwin, Cortland, McIntosh, Rome Beauty, Delicious, Yellow Newtown, and Jonathan.

On the trees, irrespective of variety, the fruit receives a continuous supply of food materials, part of which permits its growth and which goes in to form the fruit. Both before and after harvesting, the fruit goes through a breathing process affected by the temperature, food and moisture available. During all this period, both before and after harvest, the fruit respires taking on oxygen and giving off carbon dioxide similar to the cycles prevalent in animal life. When this respiration stops the apple starts to decay and is no longer edible. Such change can be arrested if the fruit is controlled in an atmosphere held at a temperature of only 30°F (−1.1°C). Most apples will keep much longer at 30°F than at 32°F, (0°C). 30°F is somewhat above freezing temperature of most varieties. The average freezing temperature of apples of all storage house grades is 28.5°F (−2°C).

A few of the varieties of apples develop internal browning in storage, especially when stored at temperatures below 36°F (2.2°C). Some apple varieties such as Rhode Island Greening, Yellow Newtown and McIntosh are often stored at 36°F to prevent this browning effect. Most other varieties, however, can be held successfully at 30° to 32°F (−1.1° to 0°C) if the fruit is harvested immediately upon maturity. Since all storage fruit continues to respire after harvest there will be some loss of weight in storage unless the relative humidity is held from 80 to 90%. Some packers even prefer, to prevent moisture loss, storing in an atmosphere of 95% RH. When this is done it is necessary to control the mold growth.

The ventilation of the cold storage rooms is usually accomplished by the circulation of air, this primarily to keep the fruit from varying widely in temperature in different parts of the room. The operators must be very careful to maintain a close temperature control in all sections of the room so that it does not vary more than 1°. If apples are kept at 30° to 31°F (−1.1° to −.6°C) in a humidity of approximately 90% their storage life can be anticipated to extend as much as 8 months for Red Delicious and Winesap apples and up to 6 months for the Baldwin, Arkansas Black, Rome Beauty and Yellow Newtown varieties.

CONTROLLED OR MODIFIED ATMOSPHERE STORAGE ROOMS

Controlled or modified atmosphere rooms are storage rooms designed to prolong the life of stored products by controlling decay, ripening processes and delaying the deterioration of the stored product. This is usually done by the control of the amount of oxygen and carbon dioxide in the room and also control of the room temperature. Such rooms, to operate properly, must be well sealed so that accurate control of the air ingredients may be maintained. Oxygen and carbon dioxide quantities are sometimes controlled naturally by the respiration of the stored product and at other times by external means. Some storage facilities are designed to reduce oxygen content, others to increase carbon dioxide content but with most designed to control the content of both gases. Practically all controlled atmosphere rooms are refrigerated to maintain desired lowered temperatures.

Storage rooms used for controlled and modified atmospheres must be carefully constructed so that they are relatively gas tight. Numerous methods are used to obtain this including galvanized sheet metal lining of the walls and ceilings with special attention to a seal at the floor. Treated plywood is also used for the lining and in recent years, sprayed urethane has been used to serve as a seal as well as an insulant. The urethane must be very carefully applied. For rooms above ground level where any building shifts can occur, sealing is difficult to maintain. Some jacketed rooms have been constructed with an annular sealed space around the room into which cold air is introduced or refrigeration coils are placed for cooling. Care should be exercised in all rooms that any penetrations of pipes, conduits, building beams or other objects are well sealed.

Safety precautions should be taken with any controlled atmosphere room. The air conditions within the room will not normally support life so that great care should be taken to permit no one to enter these rooms except when equipped with a proper oxygen mask or after several hours of purging with outside air. This purging is used when products are to be removed from storage. Safety regulations should be rigidly enforced to prevent possible injury or suffocation.

Operation of controlled atmosphere rooms may be accomplished in several ways. In the simplest form where the desired total of oxygen and carbon dioxide is 21%, the consumption of oxygen by the stored product and the production of carbon dioxide by the respiration of the product will tend to maintain a stable balance without external means.

Where more exact control is desired, external means must be used to achieve the proper balance. Excess carbon dioxide may be removed by passing the room air over dry lime or a caustic solution or through a water scrubber. This can be a manual process with the media used being replaced at intervals or automatic regenerating equipment may be used. Nitrogen generators can be used to reduce the oxygen content or oxygen consumers can be used. Increased oxygen content can be accomplished by the introduction of outside air into the controlled space. Frequent gas analysis is necessary to maintain the desired storage atmosphere. Conditions should be monitered from outside the room since interior conditions will not usually sustain life.

The greatest use of controlled atmospheric storages has been for the storage of apples. Table 21.1 shows the amount of available storage for apples or pears. Conditions in apple storage rooms may vary rather widely depending on the particular variety stored and also the geographical

TABLE 21.1. CAPACITY OF CONTROLLED ATMOSPHERE SPACE FOR APPLES OR PEARS OCTOBER 1, 1977

State	Storages	Capacity	State	Storages	Capacity
	Number	1,000 Bushels		Number	1,000 Bushels
Calif.	10	1,576	Ohio	5	211
Conn.	13	169	Oreg.	9	947
Maine	26	769	Pa.	12	1,138
Mass.	41	825	Vt.	9	451
Mich.	91	3,657	Va.	12	1,476
N. H.	18	758	Wash.	157	28,519
N. J.	15	467	W. Va.	3	212
N. Y.	96	4,662	Oth. Sts.	20	389
			U. S.	537	46,226

Capacity of refrigerated whses., March 1978 16 Crop Reporting Board, ESCS, USDA.

location. Temperatures of storages may range from 34°F (1.1°C) to 39°F (3.9°C). Carbon dioxide concentration from 1 to 7 or 8% and oxygen 1.5 to 3%.

Controlled atmosphere storage for vegetables is used mostly for vegetables in transit, mainly lettuce. It is used where long hauls consume a considerable length of time. Hauling vehicles should have a tightly sealed enclosure. Oxygen may be increased by the addition of outside air or may be reduced by the vaporization of liquid nitrogen in the cooled space. Carbon dioxide may be added from a stored supply as needed. Controlled atmosphere for vegetable storage is not used to any great extent as the results obtained apparently do not justify the expense involved. Citrus fruits likewise have not been stored in a controlled atmosphere in any significant quantities. Research and experimentation continue, however, to determine if there are advantages to any type of controlled storage.

Different localities will require different types of storage with different temperatures, atmospheric content and different methods of handling. The foregoing paragraphs are, of necessity, rather general in nature. Data should be sought from each specific area from experts in that area.

CONTROLLED COOLING ROOM FOR APPLES

The "controlled" cooling room storage for apples consists of a gas-tight room refrigerated to the desired cooling room temperature. Provisions must be made for controlling the oxygen, nitrogen and carbon dioxide content in relation to each other.

Since in ambient air the oxygen level is normally about 21%, the carbon dioxide fraction 0.30% and inert nitrogen nearly 79%, there is a related problem of respiration of the fruit as the live apples continue to respire even at 32° to 35°F (0° to 1.7°C) and consequently give off carbon dioxide.

In a sealed controlled atmosphere room under storage the apples will reduce the oxygen content and the carbon dioxide content will build up. The desired balance is an average of 2.5% to 4% of oxygen and 3% to 5% of carbon dioxide with the remainder nitrogen. Air is added if needed, to prevent a drop in oxygen below 2.5% and quantities of carbon dioxide above 5% are absorbed chemically in a caustic soda scrubber. The low oxygen level and above normal carbon dioxide level greatly inhibit the ripening of the fruit (considerably more than low temperature alone) so that its rate of softening is markedly retarded.

In practice, such controlled temperature cold storage rooms should be filled with apples before sealing for long term storage. Once sealed, a daily check should be made of the oxygen and carbon dioxide content since either one, in excess or in deficiency, may cause injury to the apples.

After removal from storage of this nature the shelf-life is several times longer than for ordinary cold storage.

In the United States this method of increasing storage life possibilities has been effectively promoted by Professor R. M. Smock of Cornell University, Professor F. W. Southwich, and others.

TABLE 21.2. APPLES IN COLD STORAGE BY STATES, JANUARY 31, 1980

State	Warehouses		
	Jan 31 1979	Dec 31 1979	Jan 31 1980
		1000 pounds	
New England	104,844	119,034	93,588
New York	228,600	297,948	219,492
New Jersey	12,920	19,113	13,567
Pennsylvania	156,295	227,032	157,914
Ohio	17,885	14,168	6,732
Michigan	186,153	219,914	161,331
Virginia	108,696	164,346	131,250
West Virginia	24,358	81,790	48,845
Washington	1,087,140	1,424,495	1,194,908
Oregon	37,750	66,277	43,978
California	60,913	93,792	76,848
Other States	36,156	61,785	40,582
48 States	2,061,710	2,789,694	2,189,035

Cold Storage, February 1980 16 Crop Reporting Board, ESCS, USDA.

COOLING APPLES AND PEARS IN STORAGE ROOMS

In the Pacific Northwest, apples and pears seldom require special precooling facilities. They are usually received and cooled in the same rooms where they are stored, because less handling is required. This procedure is commonly called "room cooling."

The product to be room cooled may be high piled manually or mechanically at the time it is placed in the room within a few days after entering the room. The fruit entering the room may be already packed or it may be loose in the containers before going to the packing line. In one method of handling, room cooling approximates true precooling; in that case, warm fruit is brought into the room and cooled before packing to remove most of the field heat and then is removed, packed and returned to cold storage for later sale. In room-cooling operations, it is desirable that the cooler provide economical storage and handling facilities and also as rapid cooling as is possible, and that subsequently the commodity temperature be as uniform as possible and be near the minimum allowable temperature for the commodity.

Any discussion of room cooling as a substitute for precooling must recognize that the process has limitations in cooling speed. First, directing air through packages uniformly on a large scale is difficult, so air velocity past the containers is rarely as great as in specially built precoolers; second, sustained room air temperatures much lower than the minimum optimum storage temperature of the commodity are not permissable. In certain types of precoolers, controlled airflow can be maintained and used to enhance the heat transfer from the commodity and low air temperatures can be used to increase the heat flow rate. This last measure presumes that the commidity will be removed from the precooler before actually cooling any lower than the minimum allowable temperature.

It should be emphasized that adequate capacity to handle the heat load is an absolute prerequisite for a good room-cooling operation.

REFRIGERATION OF GRAPES

Grapes are widely grown in the United States and over 90% are grown in California. This state produces grapes of the Vitis vinifera species almost exclusively which accounts for over 98% of the production of this European type. Of this amount, considerable quantities are utilized as table fruit.

Grapes grow relatively slowly, and should be mature before harvest because they do all of their ripening on the vine. Mature here means that state of physiological development when the fruit appears pleasing to the eye and can be eaten with satisfaction. However, grapes should not be overripe as this predisposes the fruit to two serious post harvest disorders: (1) weakening of the stem attachment in some varieties, such as Thompson seedless, which causes the berries to separate from the pedicel attachment; and (2) progressively greater susceptibility to the invasion of decay organisms. Danger of decay is also enhanced if the if the fruit has been exposed to rain or excessively damp weather before harvest.

Storage Environment

Recommended storage temperatures for Vitis vinifera (European or California type) grapes are 30° to 31°F (–1.1° to –.5°C). The relative humidity should be from 87 to 92%. Although temperatures as low as 28°F (–2.2°C) have been injurious to well-matured fruit of some varieties, other varieties of low sugar content have been reported damaged by exposure to 29°F (–1.7°C).

Storage plants that specialize in storing grapes should provide uniform air circulation in the rooms. Some plants provide precooling rooms where the grapes are cooled to 36° or 40°F (2.2°C or 4.4°C) before they are placed in storage. In some plants all of the cooling is done in the storage rooms; however, only a few have sufficient air movement to cool the fruit as quickly as desired. Ventilation is required only to exhaust sulfur dioxide and air following fumigation.

The normal change that takes place in grapes in storage involves chiefly loss of water. The first noticeable effect is drying and browning of stems and pedicels. This effect becomes evident with a loss of only 1 to 2% of the weight of the fruit. When the loss reaches 3 to 5%, the fruit loses its turgidity and softens.

Grapes are particularly vulnerable to the drying effect of the air because of their relatively large surface to volume ratio, especially that of the stems. Stem condition is very important as a quality factor and is an excellent indicator of the past treatment of the fruit. Emphasis should be placed on maintaining stems in a green fresh condition, both from an appearance standpoint and because stems become brittle when dry and are apt to break. The stem of the grape cluster, unlike that of other fruits, is the handle by which the fruit is carried, so if breakage occurs (shatter) the fruit is lost for all practical purposes even though the shattered berries may be still in excellent condition. Therefore, careful attention should be paid to those operations which will minimize moisture loss, including prompt and rapid precooling, and reduced air velocity gradually turns darker in storage. White varieties, such as Ohanez and Thompson seedless eventually turn brown but this is not due to chilling injury.

The most common cause of loss in grape storage is gray mold rot (*Botrytis* sp.). Prompt cooling, constant low temperatures of 30° to 31°F, and regular fumigation in storage are the chief aids in controlling it. Rains or foggy weather during harvest are the important contributing factors in starting gray mold infections.

The storage life of grapes is affected in large degree by the attention given to selecting and preparing the fruit. Grapes should be picked at the best maturity for storage, especially Sultanina and Ohanez. Stems and pedicels should be well developed and the fruit should be firm and mature. Soft and "weak" fruit should not be stored. The display lug is a satisfactory package for storage since it can be cooled and fumigated easily. Sawdust packages cannot be fumigated effectively, so that it is necessary to fumigate the grapes before they are packed. South African packs of wrapped bunches in excelsior have proved to be good storage packages. Precooling to 40° to 45° F (4.4° to 7.2°C) is advised for grapes that are to be in transit a day or two before reaching storage. Special care should be taken that good transit refrigeration practices are used for grapes shipped to storage so that decay will not get started. Grapes intended for storage, except those in sawdust packages, should be fumigated when shipped. It is not good practice to delay fumigation until the grapes reach a distant plant, for in the picking and packing of grapes many berries are injured sufficiently to permit mold to get started unless the fruit is fumigated promptly.

For *labrusca* (Eastern type) grapes storage temperatures of 31° to 32°F (−6° to 0°C) and humidities of 80 to 85% are recommended.

The Eastern varieties are not fumigated with sulfur dioxide because of their susceptibility to injury from it. The storage life of the important commercial varieties at 32°F is shown in Table 21.1.

TABLE 21.3. STORAGE LIFE OF EASTERN US GRAPES

	Weeks		Weeks
Concord	4 to 7	Catawba	5 to 8
Niagara	3 to 6	Worsen	3 to 5
Delaware	4 to 7	Moore	3 to 6

TABLE 21.4. STORAGE LIFE OF CALIFORNIA TABLE GRAPES

	Months
Emperor, Ohanez, *Alphonse lavallee* (Ribier)	3−5
Malaga, Castiza (red Malaga), Cornichon	2−3
Sultanina (Thompson Seedless)	1−2.5
Flame Tokay, Alexandria (Muscat)	1−1.5

TABLE 21.5. COMPARISON OF SOME RESPIRATION HEAT VALUES IN COOLING FROM 80° TO 32°F OVER THREE DAY PERIODS

Kind of Fruit	Heat of Respiration in Btu per Ton of Fruit	Kcal	Sensible Heat, Btu	Kcal
Winesap apples	8,000	2016	80,000	20160
Elberta peaches	13,000	3276	80,000	20160
Bartlett pears	19,000	4788	80,000	20160
Chesapeake strawberries	30,000	7560	82,000	20664
Florida oranges	9,000	2268	81,000	20412

CITRUS FRUIT

Introduction

Marketing studies show that losses in the distribution of citrus fruit are due to rind breakdown, decay, freeze damage, and overripeness of fruit. In addition, losses may also be caused by changes in the fruit itself. Special attention is given to better methods in the maintenance of quality of fresh citrus fruits, since loss from spoilage continues to be the chief marketing problem. Two reports point up the seriousness of decay and waste. One report states that "out of every 5 acres growing perishable citrus products, the produce of 1 acre is lost through waste and spoilage in marketing channels," and the other report estimates losses "between 10 and 30% the world over from rodents, insects, and microorganisms." The highest losses are reported in the under-developed nations badly in need of food.

Maturity and Quality

The degree of ripeness of citrus fruits at the time of harvest is the most important of the factors determining eating quality. Oranges, like grapefruit, do not improve in palatability after harvest. They contain practically no starch, do not undergo marked change in composition after being picked from the tree, as do apples, pears or bananas, and owe their sweetness to natural sugars contained when they are picked.

Quality is often associated with appearance, firmness, freedom from blemishes, thickness, texture, and color of rind. Actually, the determination of quality should be based on the texture of flesh, juiciness, content of total solids (principally sugars), total acid, aromatic constituents, vitamin and mineral content. The age of the fruit is also important, because immature fruit is usually coarse, very acid or tart, and the internal texture is ricey or coarse. Overripe fruit held on the tree too long may become insipid, develop off-flavors and possess short transit, storage, and shelf life. The importance of having good quality fruit at harvest cannot be over emphasized. The main objective thereafter is to maintain the quality and freshness.

Citrus fruit storage at the consuming and fruit express distribution centers is much alike for oranges, grapefruit and lemons. The storage atmosphere and temperature for lemons and grapefruit are very similar, each requiring a preferred holding temperature of 58° to 60°F (14.4° to 15.6°C) and a humidity of 86 to 88% RH.

The removal of the vital heat of respiration is required for each type of fruit and separate tables of this heat of respiration are given herewith.

TABLE 21.6. HEAT OF RESPIRATION OF CITRUS FRUITS AT DIFFERENT TEMPERATURES

		Btu per Ton of Fruit per Day											
		Oranges						Grapefruit				Lemons	
				California						California		California	
Temp		Florida		W. Navels		Valencias		Florida		Marsh		Eureka	
°F	°C	Btu	Kcal	Btu	Kcal	Btu	Kcal	Btu	Kcal	Btu	Kcal	Btu	Kcal
32	0	700	176	900	227	400	101	500	126	500	126	700	176
40	4.4	1400	353	1400	353	1000	252	1100	277	800	202	1100	277
50	10.0	2700	680	3000	756	2600	655	1500	378	2000	504	2500	630
60	15.6	4600	1159	5000	1260	2800	706	2800	706	2600	655	3500	882
70	21.1	6600	1663	6000	1512	3900	983	3500	882	3900	983	5000	1260
80	26.7	7800	1966	8000	2016	4600	1159	4200	1058	4800	1210	5700	1436

Adequate ventilation will remove this respiration heat and carbon dioxide.

Storage of Citrus Fruit

In general, tropical fruits do not respond to long term storage at low temperatures like those fruits and vegetables grown under a more temperate climate. Over the first 25 yr. of cold storage experience with grapefruit, the cold storage results were often most disappointing when extended for a storage period of more than a few days. Modern practice has made it possible to hold grapefruit in cold storage for 4 to 6 weeks. In California, where the climatic conditions permit the harvesting of grapefruit from the tree over several months, the crop is retained in holding rooms for only short periods of time. The trees serve as the ventilated storage space for some months. In Texas, where the control of the fruitfly demands that all fruit be removed from the tree, usually by April, then the storage period is often extended to 6 to 8 weeks and this preferably at 32°F (0°C).

Since grapefruit is a tropical product, it shows much better adaptation to total period of storage if kept at 50°F (10°C) for a short time before being transferred to the 32°F (0°C) rooms. By this procedure it is possible to hold much of the harvested grapefruit in the 32°F (0°C) rooms up to 8 weeks. Some growers adopt a standard practice of holding their crop in rooms held at 50°F (10°C) 1 week, then transferring it to 32°F cold storage at 86 to 88% humidity for the remainder of the 6 to 8 weeks. Proper stacking of the fruit containers in storage rooms is important to secure uniform air distribution.

Oranges

Prior to 1945, boxed oranges were the principal orange product for the American market. Since then canned and frozen orange juice has absorbed a large portion the crop surpluses. The 1967 data indicates that a large portion of the production of both Florida and California has been made into juice and frozen.

Florida- and Texas-grown Valencia oranges can be stored successfully for 8 to 12 weeks at 32° to 34°F (0° to 1.1°C) and 85 to 90% RH. The same requirements apply to Pope's Summer orange, a late-maturing Valencia type orange.

A temperature range of 40° to 44°F (4.4° to 6.7°C) for 4 to 6 weeks is suggested for storage of California oranges. Arizona Valencias harvested in March store best at 48°F (8.9°C), but fruit harvested in June stores best at 38°F (3.3°C).

TABLE 21.7. TYPICAL HEAT PRODUCTION OF ORANGES STORED AT THE LISTED TEMPERATURES PER TON OF FRUIT

Temp °F	°C	Heat Evolved per Ton of Fruit Btu per 24 Hr	Kcal
32	0	900	227
40	4.4	1400	353
60	15.6	5000	1260
80	26.7	8000	2016

Florida and Texas oranges are particularly susceptible to stem-end rots. Citrus fruits from all producing areas are subject to blue and green mold rot. These decays develop in the packing-house, in transit, in storage, and in the market, but can be greatly reduced if fruit is properly treated or packed with biphenyl pads. Hot water treatments effectively reduce post-harvest decay of Valencia oranges. Proper temperature is also a very effective method of reducing decay. However, once storage fruit is removed to room temperature, decay will develop rapidly. Storage of oranges is often complicated by the fact that prolonged holding at relatively low temperatures may induce the development of physiological rind disorders not ordinarily encountered at room temperature. Aging, pitting and watery breakdown are the most prevalent rind disorders induced by low storage temperatures. Generally, California and Arizona oranges are more susceptible to low temperature rind disorders than Florida oranges.

Grapefruit

There are pink, white and red flesh varieties. The fresh pink variety claims some premium in most world markets. The annual crop in the United States is often seriously affected by frost in the orchards. This often changes the amount of the fruit that must be carried in storage. Some frozen segments are carried in freezer storage and usually are preferred in salads. Grapefruit canned juice has become most acceptable and the grapefruit juicing industry has been very effective in conserving the world surplus of the annual product.

TABLE 21.8. AVERAGE HEAT PRODUCTION RATE OF GRAPEFRUIT IN STORAGE AT DIFFERENT TEMPERATURES

Temp °F	°C	Mg CO_2 per Kg per Hr	Heat Evolved per Ton of Fruit Btu per Hr	Kcal
40	4.4	4.86	1070	270
50	10.0	6.92	1522	384
60	15.6	12.60	2770	698
70	21.1	16.0	3520	887
80	26.7	19.0	4180	1053

Florida and Texas grapefruit is frequently placed in storage for 4 to 6 weeks without serious loss from decay and rind breakdown. The recommended temperature is 50° to 55°F (10° to 12.8° C). A temperature range of 58° to 60° F (14.4° to 15.6° C) is recommended for the storage of California and Arizona grapefruit.

Decay and rind breakdown are deterrents to long storage of grapefruit and may develop in fruit during storage or following removal from storage. Pre-storage treatment with fungicides will greatly reduce these problems. Also periodic inspections of the stored fruit should be made in order to terminate the storage at the very first symptoms of development of rind pitting or excessive decay.

Lemons

The lemon tree is a native of India; it has been introduced into the citrus orchards in almost all of the major tropical and semitropical zones of the world. It is somewhat more sensitive to cold than grapefruit or oranges. The handling of the lemon fruit from the tree is quite different from any of that of the other citrus fruits. It usually ripens in the winter, the fruit is actually cut from the tree long before it ripens while it is still green. A large portion of the lemon crop is picked during the period of least consumption and must be held in storage until the following summer when consumer demand calls for its distribution.

TABLE 21.9. AVERAGE HEAT PRODUCTION RATE OF LEMONS IN STORAGE AT DIFFERENT TEMPERATURES

Temp °F	Temp °C	Mg CO_2 per Kg per Hr	Heat Evolved per Ton of Fruit Btu per 24 Hr	Kcal
32	0	2.65	580	146
40	4.4	3.70	810	204
50	10.0	10.50	2310	582
60	15.6	13.5	2970	748
70	21.1	18.6	4090	1031
80	26.7	28.2	6200	1562

From the green stage the fruit must be "cured" and held in controlled temperature, and humidity conditions which involve ventilation control and adequate air circulation in the storage facility. It is usually desirable to hold the curing temperature at 58° to 60° F (14.4° to 15.6° C), never below 50° F (10° C). Temperatures above 60° F usually introduce undesirable decay bacteria, thus the storage rooms must be adequately refrigerated. At times heat may be required to maintain a narrow temperature range of 58° to 60° F within the room.

In most areas, lemons are cut from the tree while still green and after washing they are graded by color preparatory to the curing and storage. The dark green has the longest keeping property and, after curing, the best juice capacity. For long term storage the yellow has poor keeping properties and usually is not stable for more than 3 to 4 weeks, while the dark green has a normal storage life of 5 to 6 months, especially if treated with a water emulsion before they are put in storage.

Whether the fruit is of the best of the lowest quality, most lemons must go as mentioned through the process of curing during which they are held at 58° to 60° F (14.4° to 15.6° C) and 86 to 88% RH. Like all fresh fruits, lemons give off carbon dioxide while in storage and this by-product must be removed and fresh air and oxygen replaced by careful ventilation.

TABLE 21.10. TIME OF EXPOSURE (HOURS) AT DIFFERENT TEMPERATURES CAUSING INJURY OF COMMERCIAL IMPORTANCE

Color of Lemons When Exposed	Temperature of Exposure, °F (°C) 45 (7.2)	40 (4.4)	35 (1.7)	30 (−1.1)
Green	12	26	15	18
Turning	14	18	12	14
Green tip	18	12	12	6
All yellow	12	12	18	12

Lemons picked green but intended for immediate marketing, such as most of those grown in the desert portions of Arizona and California, are degreened and cured at 72° to 78° F (22.2° to 25.6° C) and 88 to 90% RH. This may take from 6 to 10 days depending on the color when picked and on the nature of the lemons.

Lemon storage rooms must have accurately controlled temperature and relative humidity; the air should be clean and should be circulated uniformly to all parts of the room. Ventilation should be sufficient to remove harmful metabolic products.

A uniform storage temperature of 58° to 60° F (14.4° to 15.6° C) is important. Fluctuating or low temperatures cause lemons to develop an undesirable high color or bronzing of the rind. Temperatures of 52° F (15.6° C) and lower cause a staining or darkening of the membrane dividing the pulp segments and may affect the flavor. Temperatures above 60° F shorten the storage life and are more favorable to the growth of decay-producing organisms. A relative humidity of 86 to 88% is generally considered satisfactory for lemon storage, although a slightly lower humidity may be desirable in some locations. High humidities prevent proper curing of the lemons, encourage mold growth on walls and container, and decay of the fruit, whereas much lower humidities cause excessive shrinkage.

Limes

The lime belongs to the citrus family and resembles the lemon in many ways. The tree, however, is more prickly and the fruit more acid than any of the commercial varieties of lemon.

In storage, limes are a typical fruit that should be held above 45°F (7.2°C) for the best results. Only a small percentage of the limes grown ever reach storage as a commercial fruit due to its extensive use in the production of citris acid and commercial lime juices where it is used as an extract in the manufacture of gelatin puddings and salads.

Bananas

Bananas are preserved by freezing for use such as in ice cream flavor bases and the preparation of bakery products, e. g., banana cream pie. Von Loesecks (1950) in his book on bananas discusses a number of varieties. The only variety commercially frozen at present is the Gros Michel. This is the yellow variety ordinarily sold in retail stores and fruit stands in the United States.

Since bananas used in the bakery usually must be mashed before mixing, very ripe bananas are usually selected for bakeshop freezing. To have available a continuous supply of very ripe bananas, freezing is often practiced some weeks prior to the periods of off-season supply, to bridge over the time gap when ripe bananas are not available on the local markets.

The principal banana varieties grown commercially are the Gros Michel, Dwarf Cavendish, Giant Cavendish, and the Claret or Red banana. Other than the red bananas, and the so-called finger varieties, these varietal differences are not generally distinguishable to most commercial consumers. Most of the bananas marketed in the United States are either of the Gros Michel or Giant Cavendish variety. Although bananas are susceptible to several diseases, those which seriously affect the economics of the industry are Panama Disease, Sigatoka, and Dry Rot or Moko.

Harvesting and Transportation.—Bananas do not ripen satisfactorily on the parent plant in the tropics; therefore, the fruit is harvested green and at a stage of development which will allow it to be transported in refrigerated carriers which will allow it to be transported in refrigerated carriers to the country of destination and arrive there still green. Another reason for cutting the banana green is that the susceptibility of the fruit to handling damage is greatly increased as ripening advances.

In order to minimize the handling of this tender fruit as much as possible, the banana industry is now packing a high percentage of production in boxes at the tropical plantations, thus eliminating many of the sources of handling damages.

To prevent stems and boxes of bananas from ripening during shipment, the holds of the refrigerated steamships are precooled so that the field heat will be removed as rapidly as possible. The fruit is reduced to a carrying temperature of about 56° F (13.3° C) (slightly higher or lower depending on variety), which is maintained throughout the journey to the domestic port. The stems and boxes of fruit are unloaded at the domestic wharf with mechanical unloading equipment.

Bananas are sold by the importer to wholesale jobbers in carload or truckload lots of tropically packed boxes weighing 40 lb. net (18 kg). Bananas should be unloaded as soon as possible after arrival at the ripening plant. Prompt unloading and careful handling will minimize damage. The fruit must be brought under control as soon as possible to assure successful ripening on a predetermined schedule which is possible only in properly equipped rooms.

Ripening.—During ripening, enzymatic changes take place in the pulp of the fruit. The pulp of the green banana contains about 20% starch. As ripening progresses, this starch is converted to sugars, principally sucrose, dextrose, and levulos. Color changes in the peel occur simultaneously with the pulp change and are also enzymatic. Rates at which these changes take place depend upon the relative activities of different enzymes, which in turn, are stimulated or depressed by the physical conditions to which the fruit is exposed.

The controlling factors in banana ripening are generally recognized to be temperature, humidity and ventilation.

Temperature.—Ripening characteristics of different lots of bananas vary with the country of origin, botanical variety, season of the year, maturity of the fruit when harvested, and other factors. It is impractical to set down precise ripening temperatures that will cover all of the foregoing variables. Ripening generally is started at a temperature of approximately 62° F (16.7° C).

Banana Ripening Rooms.—Banana ripening rooms have construction requirements similar in basic principle to ordinary cold storage vaults. Rooms must have adequate insulation, heating and cooling equipment, humidifying equipment, controls, and be as nearly airtight as modern construction techniques permit.

Room Sizes.—Banana rooms vary widely in their dimensions, depending to a large extent on the warehouse layout. Ideally any individual room should be provided for each days business. Capacities are generally based on carlot or part carlot units wich 1 carlot and 1/2 carlot sizes most generally used. Again the practice of the individual operator must be considered, as carlot shipping units may range from 500 to slightly over 800 boxes.

Airtightness.—Ripening bananas produce ethylene, volatile esters and carbon dioxide. In addition, ethylene is applied artifically at the initiation of the ripening cycle to permit use of a safe temperature range while meeting schedules. Retention of gases is essential if processing cycles are to be valid and predictable, hence the need for airtight rooms. Ethylene is explosive in air at a concentration of approximately 3 to 27%. The dangers of over-application of ethylene have been minimized by the almost industry-wide use of 4 oz., 3 cu. ft. (lectern-bottle size) cylinders.

Refrigeration.—It is desirable, even with high initial installation costs, for each ripening room to have a completely separate system connected to a single condensing unit. Although installations having standby units are sometimes used instead of independent systems. Unit coolers should be installed within the ripening room. Systems in which cooling coils are installed atop rooms, and the air ducted in, are unsatisfactory due to difficulties in maintaining room tightness. Refrigeration is normally supplied by a halocarbon refrigeration system or cold brine since even a small ammonia leak can have disastrous results in a banana room.

Heating.—During normal ripening cycles, heat is generally required only during the first 24 hr to raise pulp temperature to the desired level for application of ethylene gas. Capacity should be sufficient to raise the pulp temperature at the rate of 2° F per hour.

Humidity.—Humidity plays a definite and important role in the processing of bananas. A long program of tests was conducted in which temperatures, humidities, time period, and handling conditions were varied. In the case of low humidity conditions, it was found that bananas developed an unseen susceptibility to handling damage. High relative humidity in ripening (90 to 95%) contributes greatly to better appearance, salability and product life of bananas. Tests show that weight loss in boxes ripened in low humidity environment are much higher (up to 2 lb per box) than in boxes ripened under high humidity conditions.

Banana rooms are most often found on the premises of wholesalers where direct contact may be maintained over shipments. This equipment is not often found in public warehouses.

Avocados

The avocado is also known as the alligator pear and belongs to the tropical American group. Native especially to Central America and Mexico, of recent years it has been grown successfully in the West Indies, Hawaii, Southern Florida and Southern California.

The tree is relatively small and the fruit often develops black spots which renders it more difficult to market. A select avocado does have a tendency to age to a greying color within the flesh and especially around the seed; sometimes, however, this darkening is the result of storing at a low temperature. It is recommended that all avocados be stored at temperatures above 45° F (7.2° C) and not over 55° F (12.8° C).

The Fuerte variety is the principal avocado grown in California and is especially suited for the preservation of puree products; however some of the other varieties, especially those of the Guatemalan and West Indian plantations types, have a yellowish green color and their own characteristic flavor and can be treated to prevent discoloration in cold storage.

GUAVAS

Many persons think that guava is the best fruit of the tropics. The market for guavas in the United States is practically undeveloped. The Lupi variety contains approximately 500 mg of ascorbic acid (Vitamin C) per 100 gm; the Kauai B strain, because of its small amount of seeds; and a Hawaii University selection B-30, because of its very desirable red color, are being planted in commercial Hawaiian orchards for the express purpose of developing a superior frozen guava purée. A frozen guava purée can be used in the preparation of a number of products including beverages and flavor bases for frozen desserts.

The guava is a delicious fruit that blossoms with fragrant white flowers, the most common being of the bush tree type. The fruit is usually somewhat larger than a goose egg and is pear shaped. The guava is full of seeds, fragrant and sweet. Its principal use is in making jellies and purées, the latter being stored as a frozen product.

In North America, the guava is now grown extensively in Southern Florida and California. No great progress has been made to date in quick freezing guava slices.

MANGOS

The mango tree is tropical in nature and several attempts to introduce them in climates of occasional frosts have been unsuccessful. It is a native of Southeastern Asia where the large trees furnish much of the lumber for housing. The trees grow best on sandy soils that are very well drained; they thrive best where frequent rainfall keeps the ground cool. Under tropcal conditions the trees grow to a height of 40 ft. The mango fruit is considered by the natives of Southeastern Asia as the best it has to offer. Each fruit contains one large flat seed. The edible pulp of the fruit is soft.

The American supply comes mostly from the West Indies and Mexico although some are grown in the extreme southern areas of Florida and

California. The US Dept. of Agr. has the responsibility of inspecting the mangos as they enter the United States. In the American refrigerated warehouses they should not be stored at temperatures below 50° F (10°C), otherwise the flesh will turn brown.

PAPAYA

The papaw of the tropics is called papaya; it is a small palm-like tree with a stem similar to the palm and without noticeable branches—the leaves are its branches. Between the leaves yellow blossoms appear and in hot climates develop into a cantaloup-like fruit which has many black seeds; some varieties have fruit 15 in. long while others do not grow more than 8 or 9 in. in length. They ripen best in humid climates at temperatures between 78° and 90° F (25.6° C and 32.2° C) and should be firm ripe before shipment at temperatures between 45° and 48° F (7.2° and 8.9° C).

The natives of the tropical regions cook the unripe papaya for a food not unlike summer squash. When ripe the papaya is served as fresh fruit similar to the way residents of the temperate zones serve cantaloup. When cut in small pieces, some papaya is processed and marketed in a quick frozen state. Frozen papaya is usually stored at –10° F (–23.3° C). More of the marketed frozen papaya, however, comes to the freezer storage warehouse as puree. Large quantities of papaya is marketed as canned fruit in Number 2 1/2 cans not unlike the canned sweet potatoes of the United States.

There are extensive plantations in Hawaii and Mexico; some papaya has been successfully grown in Southern California, Florida and Texas but is strictly a tropical plant and should be cultivated in areas where the separate strains can be kept well apart in order to preserve their identity and useful characteristics. The papaya should never be stored below 45° F (7.2° C). They do not keep well even at this temperature and in prolonged storage at 45° F they become inedible.

OLIVES

While the olive tree has been cultivated for many centuries, primarily for its oil content, in the regions of the Mediterranean, the olive is utilized very extensively as a dinner food. It is not uncommon to find less prosperous workmen of the Mediterranean region munching brown bread and ripe olives with tea or coffee as their total meal. The oil content of the ripe olive is sufficient to furnish these workmen with their required fats for the days labor. In Italy and some parts of Turkey and Greece, the olive is second only to the grape as a horticultural crop.

Over many of the mountain areas, at low elevations, wild olives grow abundantly.

Historically it is of interest that, prior to the Christian era, olives and olive oil were the luxury of the wealthy, especially in the Grecian, Turkish and Italian regions. Later this use and cultivation of olives spread to Spain and thence to Mexico and other Latin American countries. As a tropical fruit fresh olives should be stored at temperatures of approximately 45° F (7.2° C) for best results. When stored at lower temperatures they have a tendency to brown.

OKRA

Okra is an edible vegetable member of the mallow family which includes the flowering hibiscus, some strains of the rose of sharon, and the cotton plant. It is extensively grown in the southern United States and some tropical countries. In its growing habits it resembles the cotton plant. Okra is a vegetable used especially to give body to soups, stews and catsups. It is highly mucilaginous. Okra is harvested and piled up, has a tendency to heat readily from its own vital heat, even to the point of steaming when packed in deep baskets. Thus for immediate storage okra should be ventilated and cooled to about 40° F (4.4° C) to prevent discoloration by its own spontaneous heating. Okra has never found an extensive market in the temperate zones except with those who have lived for a period in the southern states of the United States.

TOMATOES

Mature green tomatoes can not be successfully stored at temperatures that greatly delay ripening. Tomatoes held for 2 weeks or longer at 55° F (12.8° C) may develop an abnormal amount of decay and fail to reach as intense a red color as tomatoes ripened promptly at 65° to 70° F (18.3° to 21.1° C). Temperatures of 65° to 68° F/ (18.3° to 20° C) and 85 to 90% RH are probably used most extensively in commercial ripening of mature green tomatoes. At temperatures above 70° F decay is increased. A temperature range of 57° to 60° F (13.9° to 15.6° C) is probably the most desirable for slowing ripening without increasing decay problems. At this temperature the more mature fruit will ripen enough to package for retailing in 7 to 14 days.

Storage temperatures below 50° F (10° C) are especially harmful to mature green tomatoes; these temperatures make the fruit susceptible to Alternaria decay during subsequent ripening. Increased decay during the ripening occurs following 6 days exposure to 32° F (0° C) or 9 days at 40° F (4.4° C).

Firm ripe tomatoes may be held at 45° to 50° F (7.2° to 10° C) and 85 to 90% RH overnight or over a holiday or weekend. Tomatoes showing 50 to 75% of the surface colored (the usual ripe-ess when packed for retail) can not be successfully stored for more than 1 week and be expected to have a normal shelf-life during retailing. Such fruits should also be held at 45° to 50° F (7.2° to 10° C) and 85 to 90% RH. A storage temperature of 50° to 55° F is recommended for pink-red to firm-red tomatoes for the longest possible time with immediate consumption upon removal from storage, such as on board ship or for an overseas military base, they can be held at 32° to 35° F (0° to 1.7° C) for up to 3 weeks with some loss in quality. Mature-green, turning or pink tomatoes should be ripened before storing at this low temperature.

REFRIGERATION OF FURS AND WOOLENS

Introduction

The large investment in furs within North American and Western Europe, and their susceptibility to moth and beetle damage at high temperatures, has made cold storage a very popular and economic investment for both user and the cold storage operator. What is being said about furs is applicable to woolens except that the high insurance rate levied against furs may not apply to woolens. All such rates are based on commercial values.

Although fumigation methods can be used to control the moths and beetles, it requires more skill to preserve furs effectively by any of the fumigation processes than it does by controlled refrigeration. Both furs and woolens may be given protection in storage by one of the several methods of fumigation. While the fumigation methods of control in killing the moth and larvae is very effective, it does not immunize against reinfestation. Fumigation must be repeated at more-or-less regular intervals for continuous control of the larvae.

Furs in cold storage may be kept indefinitely without any accelerated deterioration other than the ordinary aging. Relative humidity between 55 and 65% is considered an ideal atmosphere for fur if the storage temperature is held between 35° and 40° F (1.7° to 4.4° C). Before any furs are stored for any length of time, however, the moths, beetles, and larvae should be killed. If furs are stored for 24 hr at 0° F (−17.7° C) the eggs of the moth will be completely killed. It will require approximately 4 days for the same results at 15° F (−9.4° C). Experimental studies and practices have verified that the best results can be obtained by putting the furs through repeated cycles from the low temperature of 15° F to the

TABLE 21.11. TEMPERATURE AND TIME REQUIREMENTS FOR KILLING MOTHS IN STORED CLOTHING

Storage Temp		All Eggs Dead After Days	All Larvae Dead After Days	All Adults Dead After Days
°F	°C			
0–5	−17.7 to −15	1	2	1
5–10	−15 to −12.2	2	21[1]	1
10–15	−12.2 to − 9.4	4	—	1
15–20	− 9.4 to − 6.7	—	—	1
20–25	− 6.7 to − 3.9	21	67	1
25–30	− 3.9 to − 1.1	21	125[2]	4
30–35	− 1.1 to 1.6	—	283[3]	7
				—

Source: Table AMS-57, US Dept. Agr.

[1] 50–95% of larvae may be killed in two days.

[2] A few larvae survived this period.

[3] Larvae survived this period.

warmer temperature of 50° F (10° C) on a 3- or 4-day holding temperature cycle for 3 or 4 such cycles. This might require a total of 2 to 3 weeks going through this temperature cycle program to completely kill all moths, beetles, and larvae before being moved into final 35° F (1.7° C) cold storage.

A program of introducing the furs or woolens into more-or-less permanent storage is to first give them a thorough cleaning and brushing, then freeze them for 4 or 5 days at 15° (−9.4° C), then transfer them to a 50° F (10° C) cold room at 55 to 65% RH for 2 or 3 days. Then, repeat this cycle for a minimum of 3 times before finally moving the load into a cold storage room held uniformly at 35° F (1.7° C) and 55 to 65% RH storage for the term of storage required by the customer.

Experienced managers report that they have kept furs of high value under the above cycle treatment for 20 yr. without appreciable deterioration.

Plant Design

Since, in killing moths and larvae, it is necessary to vary the temperature of the furs or woolens from 50° F (10° C) at 55 to 65% RH down to 15° (−9.4° C) for a period of several days for larvae freezing, the storage space should be varied in temperature over this range and the rooms' vapor sealing, humidity control, and insulation can be effectively varied and maintained as needed over these ranges of air quality and temperature. If, however, it is anticipated that there will be new deliveries of furs for storage at frequent intervals, then it will be more economical of power and refrigeration to build a separate freezer room to periodically carry each load down to 15° to 18° F (−9.4° to 7.8° C) for the required cycle changes, then there could be a second warmer holding room with a range from 50° F (10° C) and 55 to 65% RH for the warming period of each load cycle. Finally, this same large room would be held at cold storage temperatures of 35° to 40° F (1.7° to 4.4° C) and 55 to 60% RH for the long term holding of the furs over the seasons. Ammonia is normally avoided in fur storages due to danger of injury to furs from a refrigerant leak.

Raw Peltries

The lesser investment necessary to provide protection to furs by fumigation in preference to the refrigerated cycling down to 15° F (−9.4° C) and up to 50° F (10° C) has increased fumigant adoption by the cold storage companies. Where the investment in a freezer vault and equipment for the cycling procedure has been considered too high by the management, the erection of a fumigation vault has been substituted. When most expertly done, fumigation can be a satisfactory substitute.

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22

Tree Nut and Peanut Cold and Freezer Storage

The manager of a cold or freezer storage warehouse who anticipates annual shipments of nuts of varying keeping qualities can expect to find that those most common in American cold storagehouses are: native peanuts, pecans, walnuts, almonds, Chinese chestnuts and imported Brazil and cashews. The pre-storage harvesting treatment and carelessness in preparing any of these nut crops for delivery to the warehouses is often as important to the final quality as the cold or freezer temperatures in the storage rooms. The warehouse manager must be fully alert to the quality of the nuts delivered if he is intent on delivering a first class product from his doors.

Most edible nuts are stored in conventional storage rooms at existing cooler and freezer temperatures. Peanuts probably constitute the largest cooler storage load and large quantities are stored annually both in public and in private warehouses. Peanuts are usually removed from the shell before storage. Pecans also constitute a large storage load and are normally stored in the shell. They are stored in coolers (short time) and freezers (long hold). Freezer storage of pecans is utilized to the greatest extent following a bumper crop with depressed prices. They can be held for a long period at freezer temperatures pending higher prices in the market place.

EDIBLE NUTS IN COLD AND FREEZER STORAGE

Temperatures, relative humidity and air purity are of paramount importance to maintain top quality of edible nuts in long term cold or freezer storage. Palatability and nutritive value can be maintained for many months if these three factors are controlled in proper relation to each other.

All nuts have a high oil content and are subject to rancidity, insect and rodent infestation, odor transmittal, mustiness and weight loss by drying out if not held in a controlled atmosphere at low temperatures. Further wide variations in temperature, humidity and air purity control bring about changes in texture, color, aroma and flavor. Good cold and freezer storage houses practically preclude as storage of nuts any rooms with onions, garlic, cheese, meat, chocolate, fresh fruits and cantaloups. Packaging can have a marked effect on successful nut storage, especially in the keeping of shelled nuts. A highly absorbent package of material will present an oily saturation over the contained nuts part and this may even lead to a rancid odor. It is recommended that all nuts be packaged in nonabsorbent materials.

Well-packaged nuts can be safely stored in refrigerated rooms with candies, canned and bottled goods, rice and most dried fruits. The temperatures and humidities for nut storage vary greatly with the crop to be stored. These will be reviewed separately.

Almonds

The almond is one of the oldest edible nuts known to modern man. Genesis 43:11 commands: "Take the best fruits in the land in your vessels, nuts, spices and almonds." Since it is an early blooming tree, it flourishes best in those milder climates well-protected from springtime arctic winds. The first trees of history were apparently indigenous to Western India, Persia and Eastern Turkey but were extensively grown in Palestine and Egypt by the time of Abraham, Isaac and Jacob (1700 B.C.).

The modern US market is supplied more and more by the California Almond Growers Exchange. By 1962, this Exchange built their own cold storage facilities with the capacity of 4,000 tons of shelled almonds. They moved into the American and foreign markets with 12 grades of the shelled product and an equal number of unshelled packs.

By 1968, the Western United States, especially the Almond Growers Exchange, California, was one of the world's major producers and exporters. Spain, which has been the principal supplier of the United States, is now exporting primarily to Northern Europe and South America. The Mediterranean and Southern Asiatic countries of Iran, Turkey, Greece, Portugal and Italy are likewise increasing their annual exportation to the world markets, primarily outside of North America.

Brazil Nuts

Brazil nuts are imported from South America, primarily Brazil and Bolivia. The Brazil-nut tree is one of the largest in the Amazon Valley.

They are found in indigenous forests above the Amazon flood lines. The tree bears fruit in a huskless capsule that is 3 to 8 in. in diam that has a hard shell like covering. Each pod contains 12 to 20 nuts arranged as segments within the pod. Brazil-nut trees prefer a well drained clay soil on the higher levels away from swamps and streams. Brazil nuts do not store well, especially in their Brazilian climate and much of the exporting is done in the original pods to be shelled, classified and packaged preparatory to being placed in cold storage. In a typical year 8,000 to 10,000 tons of in-shell Brazil nuts are imported to the United States from a total exportation averaging 25,000 to 30,000 tons a year from Brazil and Bolivia of in-shell Brazil nuts which is supplemented by approximately 5,000 tons of shelled Brazil nuts that are exported by Brazilian and Bolivian merchants.

Nearly all Brazil nuts are harvested on the ground and picked up by the natives. Since the uncultivated native trees are very numerous and are highly productive, the total annual collection is only a small percentage of the annual available tree crop. The Brazilian traders and commercial collectors export part of these from their own trading posts, then deliver large quantities to the shelling centers at Belem and Manaus, Brazil, and to four shelling plants operating in the Bolivian section of the Amazon Valley. Currently the trend in both Brazil and Bolivia is to do their exporting of shelled rather than in-shell nuts. This furnishes income to a domestic labor force of 6,000 to 10,000 workers of the Brazil nut industry of these two nations, and increases the profit to the Brazilian and Bolivian merchants. Many thousands of trees remain unharvested each year, the annual production depending mostly on the foreign demand. The nuts are not economically stored in the Amazon Valley thus the annual carryover of the crop is nearly nil. In the American and European markets Brazil nuts are sold in the shell or packaged as shredded, salted, candied, roasted or ground. Woodroof (1967) reports the proximate composition of the Brazil nut in Table 21.1.

The Brazil nut has a short shell-life, and unless kept in appropriate storage conditions will soon show marked decay. For local nut marketing in the United States and Europe, it is usually distributed at the Christmas season of the year when the new crop nuts are shipped under seasonal low temperature conditions.

TABLE 22.1. COMPOSITION OF BRAZIL NUTS

Component	%
Moisture	2
Protein	16.3
Extract oils	68.3
Fiber	6.6
Ash	3.61

Cashews

The cashew tree is native to the American tropics. It is a low spreading evergreen that produces many products. The principal import to the United States and northern Europe is the roasted cashew nut which comes today mostly from India.

The nut is less than 1 in. long and of kidney-like form and occurs in small pods varying in size from plum to pear. The nut is submerged in a caustic oil within the pod. This oil is toxic and strong enough that the people of India use it as a wood preservative to protect floors and walls against white wood ants. The Indians also use this oil in pharmacy to regulate stomach disorders and for gargles.

The nut is first roasted to drive off the caustic taste and odor and make the nut nontoxic.

Today, the imports of roasted cashew nuts to the United States are rapidly increasing but on account of the nature of the liquid within the cashew pod, the US Public Health Department has had to enter into an agreement with the Cashew Export Promotion Council of India to enforce compulsory pre-shipment inspection and quality control.

Cashews keep well in cold storage. Most shipments of the salable nuts come in vacuum packed cans or bottles and are stored below 45°F (7.2°C). When not vacuum packed, they are placed in hermetically sealed metal cans with carbon dioxide gas replacing all air in the containers. Today, the cashews as a tree nut is second only to almonds as a product of export and import. In a normal year, the cashew imports to the United States exceeds 50,000,000 lb.

Chestnuts

Currently in North America most of the cultivated chestnuts are of the Chinese variety. Imported chestnuts may be of the European or Japanese species. For many generations the American chestnut virtually controlled the United States market, but just subsequent to World War I the American chestnut trees which were primarily distributed within the Appalachian mountains were killed by the chestnut blight called *Endothia parasitica*. This completely wiped out the American chestnut. The wood for further commercial consideration of the American chestnut was salvaged for lumber and for the production of tannic acid, even the second generation sprouting from the older tree stumps became reinfected with this fungus and died within a few years.

The Chinese chestnut has taken the place of the American chestnut in US production. The US Dept. of Agr. carried on an extensive campaign introducing Chinese chestnut seed from Georgia to the West Coast and as far north as Maryland and Virginia. The Chinese chestnut has a thin skin and the kernel or meat separates readily. The trees do well in any area but must be protected from the late spring frosts to assure fruiting. The tree itself will withstand low temperatures to −20°F (−28.9°C). The young trees will produce heavily even by the tenth year of growth. Fortunately the Chinese chestnut is resistant to the fungus that destroyed the American types.

The nuts vary widely in quality and great care must be taken in curing to maintain the palatability. The nut must not be permitted to dry out completely but must be reduced to 15% moisture to change part of its starch content to sugar. The best cured Chinese chestnuts developed to 5% sugar in the kernel although frequently late cured Chinese chestnuts may show as high as 10% sugar. While the history of Chinese chestnuts production in the United States is not over a sufficiently long enough period to provide accurate data, healthy trees are expected to produce 70 lbs of nuts in the shell by the 15th year of cultivation.

France, Italy, Portugal, Spain and Japan have been importing Chinese chestnuts for the past 40 yr during the period of low gross production of the nuts within the United States. In a normal year the total imported crop will exceed 7,500 tons, mostly from European sources.

Walnuts English (Persian)

These walnuts by heritage might well be named Judean. History records extensive fields in Solomon's gardens at Ethan six miles from Jerusalem. The original stock moved first to Persia, thence to England, to Carpathian Poland and to California. In most western markets they are sold today as "English" but in Asia they are identified as Persian, and in the United States as either "English" or "Californian."

Over the intervening centuries, a strain of the Persian walnuts has been acclimated to the protected valleys of the Carpathian mountains in Poland and Austria and these are now finding an acceptable climate to produce in New England and Ontario even at temperatures as low as −30°F (−34.4°C). These oriental walnuts produce best on deep and loose soil, preferably many feet above heavy or rocky subsoil. Other than the Carpathian varieties oriental walnuts grow best in warm but not too hot climates, preferably between 80° and 90°F (26.7° and 32.2°C). Excessive cold may kill the English and Californian varieties.

Storage of Persian Walnuts.—Nearly 90% of English or Persian walnuts are marketed as meats. Preparing them for the sheller is a prestorage process. Most walnuts of these varieties contain as high as 45% moisture. Before shelling this moisture content must be reduced greatly to stabilize the kernels against molding, discoloration and rancidity. The optimum kernel moisture is just about 4%. Before shelling, commercial processes may include rehydration over a short period to stabilize the meats.

English walnuts are much more susceptible to rancidity and darkening of kernels than American black walnuts. High humidity, excessive light and heat, and oxygen, destroy their flavor and salability. The most stable condition of the kernels can be maintained with 3.1% moisture. The free world production of Persian walnuts in the shell is approximately 160,000 tons, of this total tonnage about ½ is outside the United States and a similar tonnage within continental United States. The countries outside the United States export about 45% of their production.

Black or American Walnuts

The black walnut is an indigenous nut tree to the deep well-drained well-limed soils of North America; they were found on this continent by the early colonists and had been an annual crop harvested by the American Indians as edible food nuts for many generations. On good soil they are productive within 5 yr after planting. On Eastern and Midwestern United States soils and over the clay land Southern States from Texas to Virginia we find the heavy producing areas of American black walnuts. On account of the rapid growing characteristic of the walnut trees and the high value of walnut wood for furniture manufacture, walnut forestry has been very successful. The annual nut crop contributes very profitably to the maintenance cost of the plantings until the wood can be claimed for valuable sawlogs. As a private venture, the investment return on a walnut forest is not attractive since it usually requires 40 to 50 yr for the complete planting cycle to render full return. Such an investment is more likely to attract a corporation than a private individual.

While there are now available some one hundred varieties of American black walnuts, the nut growers associations are partial to the Stabler, the Thomas and the Ohio varieties. This decision is based upon the productivity, the recovery of nut meats per bushel and the excellency of the product. Some of the one hundred varieties have exceedingly hard shells and small nut meats. In regions where there is some choice even the squirrels prefer to bury the walnut varieties that have hard, thick shells.

Ground walnut shells are used as a substitute for air blasting metals. In engine cylinders the hard wood dust will cut away the carbon but not the metal and serves in burnishing the surfaces cleaned.

Black Walnuts in the Food Industry.—The meats of the black walnut are considered of high value in flavoring ice cream, candies and cakes. In the market place the black walnut growers experience a seller's market since the demand almost annually exceeds the supply. Since the black walnut flavor is somewhat more distinctive than even the pecan, the latter can be considered the nut meat substitute for black walnuts.

Storage of Black Walnuts.—In cold storage held at 70°F (21.1°C) or below and 75% RH black walnuts keep well for more than 2 yr without any distinctive flavor loss. The more critical period of their storage is in preparation. It is desirable to remove the hull as soon as it will loosen from the nut. The high percentage of acid-like liquid within the hull will darken the meat if left on the nut too long.

Suitable hullers are available, both hand and power operated. For many years corn shellers of the Midwest were employed to do extra duty in shelling walnuts. Black walnuts should be removed from the hull within two weeks after collecting.

For the market the kernels are classified for (a) large fancy; (b) large medium; (c) regular medium, and (d) small.

Filberts or Hazel Nuts

Hazel nuts are native to North America, Europe and Asia, but do not appear south of the equator. In Midwestern and Eastern United States, they are found indigenous to these areas especially on the edges of uncultivated wooded lands and stock pastures. They usually occur as a tall bush or bushy tree-like shrub.

The European hazel nut under the name of "filbert" has been extensively cultivated as a food supplement and both trees and nuts vary widely in size and productivity. In Asia, especially on the southern Black Sea Coast in Turkey, hazel nuts are indigenous as trees and constitute a profitable export especially in the region of Trapizan in eastern Turkey on the Black Sea. Filbert or hazel nut culture has been practiced for 3,000 to 5,000 yr by the Chinese, the Greeks and the Persians, primarily within the north temperature zones.

North American countries import some 3,500 tons of shelled hazel nuts and 1,200 tons of nuts in the shell annually. The principal imports are from Italy, Turkey and Spain. The United States in turn exports approximately 500 tons of hazel nuts, their principal market being Germany, Canada and South America, The total annual world production is estimated at 150,000 short tons with Italy leading with 70,000 short tons.

In harvesting it is advisable to pick the nuts from the shrub or trees to avoid their falling onto moist or wet ground cover and getting wet. The tannin of the shell penetrates into the nut and imparts a bitter taste.

Commercially the freshly picked nut is dried either by the sun or in 100°F driers. These driers appear in many designs; most often the design is a copy of simple evaporated fruit sun driers.

Filberts are stored in the shell in rooms at 65 to 70% RH and a temperature of 32°–35°F (0°–1.7°C). When shelled they keep exceptionally well for 2 yr when stored in carbon dioxide gas even at temperatures up to 50°–70°F (10°–21.1°C).

Peanuts

Peanuts have a much greater market appeal in North America than in Great Britain and Europe. For most Europeans, they are known as groundnuts. Several attempts have been made by the British to extend their cultivation to African countries but the great mass of the peanut culture of the world is in North America, especially in the states of: Virginia, North and South Carolina, Georgia, Alabama, Texas and Louisiana. In the United States, the annual crop may exceed 160 million pounds of nuts in the shell. The shell may vary from 30 to 60% of the gross weight in-shell, this variation being due to variety selection.

As harvested, the average crop produces for the world market, shelled nuts that are 44 to 48% oil; 25 to 30% protein; 5 to 7% water and 2 to 4% carbohydrate with smaller quantities of phosphorus, calcium and niacin. Of the edible peanuts harvested in the United States over 50% goes into peanut butter; 22% into peanut candy; 25% into salted peanuts.

For storage they are usually held at 32° to 36°F (0° and 2.2°C) and 65% RH.

In world production one variety is primarily produced for oil, the other for edible stock. It is estimated that of world production of peanuts 10,000,000 tons go into oil production. In North America, however, more than 65% of the peanuts grown go into the shell trade, either as plain or salted roasted peanuts, peanut butter and peanut candies.

The process of preparing for edible trade includes cleaning, shelling, blanching and roasting, then refrigerated in cold storage at a maximum of 36°F (2.2°C) and 65% RH.

Peanuts in Storage.—Bissell and Du Pree (1946) reported that shelled peanuts in heavy cotton bags were free of insect infestation but in jute bags were heavily infested after storage at 80°F and 65% RH. The test room itself was heavily infested with insects in which this observation was made. Thompson *et al.* (1951) found that shelled peanuts in 120 lb burlap bags could be stored for 5 years at 0°F (−17.8°C) for 2 years at 32°F (0°C), for 1 year at 47°F (8.3°C), and for 3 months at 75°F (23.9°C). All of these tests were at 65% RH.

Mather *et al.* (1956) found that the optimum condition for cold storage of peanuts in gunny sacks was 32°–35°F (0°–1.7°C) if held at 85–90% RH. After 9 months of storage under these conditions the shipment was 100% marketable and appeared in excellent condition.

Pecans

Although first grade pecans bring one of the highest prices of any other food nuts on the American market, there is great carelessness in many communities in the collection of the annual crop from the producing trees. This carelessness may be noted from Georgia to Central Texas and into Northern Mexico.

Especially in the regions of high rainfall and heavy grass groundcover high quality nuts are too often allowed to lie on the damp ground for several days; the result is dark colored nuts with a musty taste.

There are strains of pecans acclimated to upper Ohio and Mississippi Valley but those varieties have small meats and are not of great commercial importance in competition with the Gulf Coast and Southwest varieties.

The US Dept. of Agr. has announced specific instructions on grading and harvesting quality pecans and recently has developed mechanical tree shakers to reduce the time of picking. Woodroof (1967) of Georgia Experiment Station, experiment, Georgia has devoted much of his two volumes on tree nuts to the grading process and storage of pecans. Any storage house manager who contemplates storing pecans should consult these volumes.

Since the annual volume of exported US pecans exceeds 1.5 million pounds of the shelled crop and a similar weight of in-shell nuts, there is a demand for pecan holding rooms of both the in-transit export and domestic types of both cold and freezer storage. The heaviest importers are Canada, Great Britain, West Germany, Finland, Australia, Japan and South Africa, Sweden, South Arabia, The Netherlands and Switzerland, and Venezuela. Of the five principal in-shell nuts produced in large volume in North America only almonds bring a higher average annual price.

Pecans and Pecan Warehousing.—The pecan has been named the most important nut bearing tree in North America. It is a species of the hickory. It is native to southwest United States and northern Mexico. These were planted in this region under Indian culture. The Spaniards found trees of several hundred years production in the sixteenth century, especially along the higher river lands of South Texas and Northern Mexico. Before World War I the American pecan was promoted primarily for local cultivation and regional marketing.

While many orchards existed from Georgia to New Mexico by 1920, widespread cooperative marketing and processing did not become effective in the producing arena until 1930.

Rapid advances have been made in pecan cultivating, harvesting, curing and warehousing during the past half century, while before World War I the pecan was given over to local or area consumption, and was sold at a low price per bushel or per pound. The principal assurance of pecan quality to the purchaser of the product was based on the historical record of the established grower to deliver carefully harvested and properly cured nuts in the shell as in previous years.

In this early period most of the shelling and packaging was done in Northern consuming areas. Itinerant or local buyers purchased thousands of bushels in the shell in the Southern growing centers then shipped them to the shellers of the Northeastern United States. These buyers depended upon their own organoleptic inspection and established records of the grower to supply an acceptable product.

Only a limited number of acceptable shelling machines were on the market until 1935. Most corporations engaged in packaging shelled pecans considered their shelling equipment designs as their secret of the trade. By 1940, however, several highly improved shelling machines had been invented for producing acceptable pecan halves at buying centers from San Antonio, Texas to Albany, Georgia and Northward to Memphis, Tennessee and the Tennessee River Valley and Southern Oklahoma and Arkansas.

TABLE 22.2. GRADES OF PECANS AS DELIVERED INTO COLD AND FREEZER WAREHOUSES PECANS-IN-THE-SHELL OFFICIAL STANDARDS CLASSIFICATION FOR SACKING AND OTHER PACKAGING

Classification	Average Pecan Count per Lb	Average Pecan Count per Kg
Oversize	52 or less	115 or less
Extra large	53 to 60	116 to 132
Large	61– 73	133 to 161
Medium	74– 90	162 to 198
Small	91–115	199 to 254
US Standard Shelled Pecan Grades:		
(A) US No. 1 halves		
(B) Commercial halves		
(C) US No. 1 pieces		
(D) US Commercial		

Pecans are more sensitive to taste and quality change than walnuts, peanuts or almonds. During the harvesting period, especially that from the tree to the sheller, the quality of the nuts that reach the cold and freezer warehouse will depend largely upon the growers' and brokers' handling. They must pass through the normal curing process, thence to

TABLE 22.3. US STANDARDS SHELLED PECAN HALVES CLASSIFICATION

Grade	Halves per Lb	Halves per Kg
Mammoth	200–250	441– 551
Junior mammoth	251–300	442– 661
Jumbo	301–350	662– 772
Extra large	351–450	773– 992
Large	451–550	993–1213
Medium	551–650	1214–1433
Topper	651–750	1434–1653

the packing room, and/or the sheller for delivery, to the warehouse for classification for quality for the national market. Even a few hours delay beneath the pecan tree on damp ground may be sufficient to produce an inferior product and a definite price downgrading.

Pecan pieces are graded by the dimension of round sieve openings. These sizes are from ½ in. sieve round opening classified as Extra Large to the descending scale openings of Large, 5/16 in.; Medium, ¼ in.; Small, 3/16 in.; Midget, ⅛ in.; and Meal, 1/16 in.

Pecans are of a more distinctive flavor than most other nuts but they are also subject to a higher rate of deterioration than any other of the edible nuts, such as black or Persian walnuts, almonds and peanuts. All nuts keep better, however, when frozen, especially if they have been cured to less than a 6% moisture content.

TABLE 22.4. SOME SELECTED STORAGE CONDITIONS OF COMMERCIAL NUTS AND RESULTS[1]

Product and Package	Storage Temperature °F	Storage Temperature °C	Storage % RH	Safe Storage Period Months
Almonds, unshelled in cloth bags	32	0		12
Almonds, shelled—in cans	32	0	65–75	20
Brazil nuts—shelled	32	0		6
Cashews	45	7.2		12
Chestnuts	32	0		12
English or Persian walnut, shelled—vacuum packed	32–20	0 – –6.6		23
American black walnut, shelled—cloth bags	32–20	0 – –6.6		20
American black walnut, shelled—vacuum packed	32–20	0 – –6.6		36
Filberts, shelled—polyethylene bags—sealed	32	0		12
Peanuts, shelled—120 lb burlap bags	0	–17.8		60
Peanuts, unshelled—gunny sacks	32	0	85–90	9
Peanuts, shelled and exposed to air	32	0		6–10
Pecans, shelled—vacuum packed	32–20	0 – –6.6		24–36
Pecans, shelled—air tight containers	0–20	–17.8 – –6.6		24–36
Pecans, unshelled—less than 7% moisture in metal cans	0–20	–17.8 – –6.6		60
Pecans, unshelled—less than 7% moisture, exposed	32–20	0 – –6.6	75	12

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[1] From Woodroof. Foods for shelter storage, Georgia Experiment Station (1960).

On account of their high oil and low water content the freezing point of common edible nuts is low. Woodroof shows Persian walnuts begin to freeze at 20°F (−6.7°C) and pecans at 19.6°F (−6.88°C). With low moisture content pecans have a wide freezing range that might extend over 20°F. In other words, while any shipment of pecans may begin to freezer at 19.6°C, it will probably be 0°F (−17.8°C) before the final moisture portion of each nut is completely solidified or frozen. For above freezing pecan storage, nuts held at 33°F (.6°C) for up to 6 months periods are satisfactory at 65 to 75% RH in controlled atmosphere rooms.

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23

Specialized Storage and Process Rooms

The greatest percentage of products stored in public cold storages can be stored under standard conditions maintained by the warehouse in the various cold rooms. As a rule, the larger warehouses will have several areas of different temperatures which will accommodate most commercially stored products. There are some products, however, that need special treatment and are handled in sufficient volume to justify a specialized room. Some of these specialized conditions will occur often enough to merit mention in some detail.

TEMPERING ROOMS

There are some products stored at cooler temperatures that are normally shipped out of the warehouse in nonrefrigerated transport. Canned milk and a few other canned and packaged products fall into this category. Removing canned or packaged merchandise from cold storage and shipping at high outside summer ambient temperatures can pose a problem whenever the dew point of the outside air is higher than the product temperature. Sweating will occur on the outside surface of the product package which can ruin labels and cause other damage. To prevent this damage, a tempering room is required in which products can be warmed at low humidity conditions to prevent condensation. In any large cold storage operation, this room can be very versatile and useful to the operation of the plant.

A tempering room is usually a regular cold storage room as far as insulation and vapor sealing are concerned. Controls and equipment, however, are somewhat more elaborate than a normal cold storage room would use. Extra surface is required in the cooling units and a source of heat is also required. Direct expansion units with a suction temperature as low as 0°F (−17.8°C) are desirable to give a wide range of control. Suction pressure on the refrigeration units may be varied by means of a modulating back pressure regulator controlled by a humidistat. To raise the temperature of the room and product, a heating coil is required. This coil is best served by a source of hot water in the range of 160° to 180°F (71.1° to 82.2°C) and a motorized valve controlled by a thermostat can be used as a control. Thus, the dry bulb setting is controlled by the heater coil and the humidity by the cooling coil. As lowered humidities are called for, as at the start of a tempering cycle, the cooling coil operates under a lowered (colder) suction to condense moisture from the air. To maintain dry bulb temperature, the heater coil is operated to offset the cooling so that the resultant air in the room is warm and dry. The heating coil must be large enough to overcome the capacity of the cooling coils plus enough capacity to warm the room. Usually a chart can be prepared giving various humidity-temperature-dew point relationships so that the controls can be set for the desired results. Products are normally tempered to final desired conditions over a period of a couple of days. Temperature control of the room is usually raised in several steps over the tempering period. A thermometer placed in the product near the center of the stack should be used as a criterion of when the product may be shipped. The function of the tempering is to raise the product temperature above the highest outside anticipated dew point temperature.

Cooling units should be equipped with some method of defrost since at the start of the tempering process, the refrigerant temperature may be quite low and considerable frost can accumulate on the coil surface. As the temperature is raised, the refrigerant temperature will normally also rise and will eventually be above freezing so that liquid condensate will occur at that time without the necessity of defrosting.

The heating coil may be a separate unit with its own fan. It is not necessary that it be incorporated in the actual cooling unit. The dry cold air from the refrigeration unit will mix very rapidly with the warm air from the heating unit and the dew point conditions in the room will be the same at all points in the room since the air mix will be almost instantaneous. Separate heating and cooling units can be mounted along one wall of the room. If they are ceiling units, they can blow out into the room at ceiling level with no duct work. If they are floor units, a gooseneck duct to carry air up for discharge at ceiling level is usually all that is required.

Since tempering rooms are operated at low humidity conditions, care should be taken that the room insulation is tightly sealed and also that the doors have a tight seal when closed so that excess moisture will not flow into the room.

HIGH HUMIDITY ROOMS

Tempering rooms can also be used for high humidity rooms by reversing controls. Since these rooms are equipped with more than normal cooling surface, a very close temperature difference can be maintained between the room temperature and the refrigerant temperature and very little moisture will be removed by the refrigeration. With a modulating thermostat instead of a humidistat controlling the modulating back pressure valve, any set temperature can be maintained with the highest possible evaporating temperature of the refrigerant. For a variety of humidity settings, the heating coil may be controlled by a humidistat and almost any degree of humidity may be maintained under cooler conditions.

The versatility of a tempering room makes it a very desirable addition to any medium or large cold storage plant. Size can be whatever is desired. A good size range will be with a capacity to hold from 5 to 15 or 20 carloads of merchandise. Location of the room near the machine room is desirable from the standpoint of being near a source of heat and also convenient for frequent checking by machine room personnel when required. A simple control panel can be located at a convenient point with proper switches to control operation under any category desired. It is also desirable to add temperature and humidity indicators to the control panel.

CANDY AND SPECIAL HUMIDITY ROOMS

Various types of candies are stored in cooler rooms. Temperatures required will vary depending on what the candy manufacturer specifies and also on the type of candy being stored. Many types of candy are stored after manufacture during the year to be drawn out during holiday seasons when demand is high. Humidities are usually low and require rather exacting control. Recording temperature and humidity indicators are very often required to assure continuous supervision. Many types of candy require holding in a room at a temperature near 50°F (10°C) and about 50% RH. Hard candies are kept at various specified temperatures and humidities to prevent them from becoming sticky or discolored. Chocolate candy also has a tendency to lighten in color and to become color streaked if not held within certain temperature limits. Almost all candy requires a humidity somewhat lower than can be accomplished with cooling coils alone.

To obtain the low humidity required in a candy room, some type of reheat is usually required. In some warehouses candy storage is a sizeable load and it is desirable to have space for this type of storage. The simplest form of refrigeration for a candy room consists of a cooling fan-coil unit with an electric heater mounted on the face of the unit.

Temperature control is obtained by a thermostat operating the cooling coil and humidity is controlled by a humidistat operating the reheat coil. Control and operation is similar to a tempering room except that the requirements are not as severe and control need not be as elaborate. Several cooling coils with reheat mounted along the side of the room at ceiling level or floor units with gooseneck ducts to ceiling level make a good room that can be controlled easily.

In areas of high electric cost, electrical heating for reheat may become quite expensive to operate and other sources of heat become desirable. Quite often, even in large warehouses, the candy rooms may be operated from a separate refrigeration unit since quite high refrigerant temperatures are sometimes used in comparison to the standard cold storage refrigerant temperatures. In these instances, or where the candy room is close to the machine room, a source of heat may be at hand from the compressor discharge gas. If a complete self-contained system is used, condensing coils can be mounted on the face of the cooling units and by means of solenoid valves, hot gas can be diverted from the regular condensers to the coils on the face of the cooling units as a reheat source. By splitting the reheat condensing coils into several circuits or multiple units, step control can be obtained. Of course, hot water or steam may also be used for reheat, if available. Steam is probably the least desirable source since the temperature level is high for reheat.

Film and paper storage rooms also require a rather high degree of humidity and temperature control similar to that of the candy room although the dry bulb temperature may be somewhat lower than for candy. Construction of these rooms is similar to the candy rooms.

CONSTRUCTION AND OPERATION

In all specialized rooms where humidity is held at variance from the outside or natural humidity, careful sealing of the rooms and door openings is mandatory and good vapor barriers are a necessity in the room construction since rather great vapor pressure differences between inside and outside will be encountered. Where a room is consistently used at a low humidity and relatively high temperature (50°F) (10°C), it is sometimes advisable to use somewhat less than the normal thickness of insulation in the ceiling and walls so that there will be an increased sensible heat load to allow the refrigeration to operate to dehumidify the room. This will tend to lessen the auxiliary heating required. Where outside temperatures reach and hold low levels for extended periods of time, considerable amounts of auxiliary heat may have to be added to obtain a humidity balance. In cold regions, the insulation thickness used in the room should not be decreased.

In low humidity storages, merchandise movement is not rapid and loads are rather stable over long periods of time. In such instances, manual setting of controls can sometimes be used since load conditions will not vary or change except slowly especially in large rooms. Careful and frequent checking is normally required for manual control conditions and savings in control equipment cost are usually more than offset by increased labor cost.

STORAGE OF MISCELLANEOUS PRODUCTS

Edible Nuts[1]

Storage of edible nuts at cooler temperatures has been done for many years. A few years ago the biggest storage load of edible nuts was probably shelled peanuts. They were stored at temperatures of 32° to 35°F (0° to 1.7°C) and 80 to 85% RH. The shelled nuts were stored in bags weighing 120 lb. Peanuts are easily stored and are not seriously affected in the presence of refrigerant gases. Refrigerant leaks in direct expansion coils will not change the grade of peanuts normally unless actual liquid refrigerant burns the nut.

Pecans are very susceptible to ammonia vapors in the cooler storage room and for this reason, most pecan storage rooms are chilled with brine in plants where ammonia is the prime refrigerant. Pecans are stored in coolers at the same temperature conditions as peanuts but are usually stored in the shell. Pecan storage assumes rather large proportions in the south and wouthwest.

In recent years, both peanuts and pecans have been held in freezer storage. The storage life of these nuts in the shell is about five times as long as can be attained in a cooler. More pecans are held in freezer storage than peanuts due to the fact that the unit price is much higher and greater profits accrue when they are held and sold in a year when the fresh crop is small and prices are high. Pecans are susceptible to ammonia vapor in the frozen state so that brine refrigeration units are usually used in ammonia plants. The presence of ammonia tends to blacken the pecan meat. This does not alter the flavor but the off color characteristics will often change the grade downward making the nuts less valuable.

Pecans or peanuts may be frozen in an ordinary freezer holding room. Fast freezing of the product is not essential so that only a moderate amount of excess refrigeration over the amount required for holding only is required. After the nuts are frozen, minimum storage tonnage is required since nut rooms are stacked high and the nuts occupy a great deal of the total cubage of the room. In some instances where a long hold is required, pecans may be hand stacked to obtain greater stored tonnage in a given area. This is true in rooms with high ceilings where it is desired to utilize maximum space and the storage period is long and the lots of nuts are large. Local labor costs will determine the feasibility of hand stacking.

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[1] For further recommendations of edible nut cold and freezer storage see Chap. 22

Potatoes

The American public has an abundant annual supply of both Irish and sweet potatoes. Both types originated in Central and South America. The Irish name became appended to the now principal staple vegetable food of Western Europe and North American when it was introduced to Ireland to meet the repeated threats of a famine on the island. The threat was met so successfully that since that period, the tuber which more properly should be named Peru potato is called Irish.

The sweet potato is also of an Indian (probably Inca) origin of Central and South America and appears in may variations. The most popular of which is the yam. The yam variety alone of the sweet potato family can boast 150 species.

Storage.—While the annual production of the "Irish" potato in North America alone totals over a half billion bushels annually and the sweet potato not over 50,000,000 bu since both are harvested in the late summer and fall, there is a great demand for storage of several months duration to level out the delivery to the grocers and to the processors of many types of human foods that appear on the American market.

The approximate analysis of White Irish potatoes is given below:

	%
Water	65 to 85
Protein	1 to 4
Carbohydrate	15 to 30
Solids	12 to 35

Potatoes change in many characteristics in storage especially if not well-cured after digging. This will include maintaining the storage room at 50° to 60°F (10° to 15.6°C) and 85% RH to prevent dehydration. If properly cured their weight loss is under 5% in the first month and 9% in 6 months.

Sweet potato storage usually requires a separate room both for curing and for long-term storage. Most commercial brokers of yam or other sweet potatoes will specify the temperature and humidity storage they anticipate necessary to preserve their shipments.

Many early growers of Irish potatoes tried to avoid the extra cost of commercial warehousing and stored their year's crop on a selected dry ground area, then covered the accumulated pile of potatoes with burlap blankets. The entire pile was then covered with 6 to 8 in. of sandy field soil to protect it from early frost and fall showers. Such storage in the hands of competent, experienced growers was often very successful. But even the best of conditions was subject to unanticipated heavy rainfalls and subsequent freezing weather even to the concurrent fall of snow, with subsequent ice formation.

SUMMARY

With rising power costs and the escalation of construction prices in general, it behooves the prudent cold storage operator to analyze rather carefully any specialized room that may be requested. Special conditions can be expensive, both to operate and maintain. Construction costs can also mount rapidly. The warehouse management should be sure that any deviation from standard conditions will be utilized for a long enough period and at a sufficiently high rate to justify the expenses involved as well as operating and maintenance cost.

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Safety of Workmen and Safe Refrigeration Plants

More than 60% of the accidents occuring in cold and freezer storage including transport and refrigerated processing are preventable. The management of cold and freezer storage warehouses and the related facilities, including the superintendents of the transport and refrigerated processing facilities can prevent probably 50% of the industrial hazards by judicious planning and design. The other 50% can be charged to the ignorance and carelessness of the employees and the related service groups' transporting, handling and processing the cold and freezer storage items of modern storage warehouses.

The management and supervisory personnel are obligated to make all equipment, facilities and service arrangements as foolproof as possible, but the employees must serve the management in good faith and not bring on themselves unnecessary injury to earn a vacation or to receive insurance compensation illegally. Eternal vigil of machine builders, warehouse managers and all employees of the cold and freezer warehouse facilities is essential if accidents are to be maintained at a minimum.

SOME GENERAL INSTRUCTIONS

All moving machines should receive careful inspection at scheduled periods, in addition to the casual daily inspection by the operating crews. Gears should be completely enclosed, set screws counter-sunk, power belts completely guarded and open vats and wells fenced or covered. Emery wheel guards should be built of steel plate and so installed as to discourage removal of the guard. Emery wheel operation is not too safe even when all precautions are taken, but a completely steel-guarded wheel and approved grinding goggles on every operator should be required in every plant.

Crushing of the hands or feet by falling or shifting crates and boxes is a common accident in refrigeration plants. Repeated educational talks to the personnel are necessary to reduce this hazard to a minimum. Slippery floors cause many falls and injuries. Non-slip shoes are recommended.

Severe electrical shock, often fatal, is common in carelessly managed plants. All lamp cords and all switches and electrical connections should be examined frequently. Where moisture and brines are present on floors, fatal grounding through the human body is very possible when exposed electrical connections can be reached by the operator's hands or touched by his head. Extra care should be taken in plant construction to see that all grounding provisions of the electrical code are faithfully followed.

Great care should be exercised in working with toxic refrigerants, especially in machinery rooms where there is danger of a rupture of a valve or a cylinder head. Some of the worst accidents recorded in refrigeration history have been brought about by careless or uninformed operators not understanding the hazards inherent in starting or stopping a compressor operating on a toxic refrigerant. Compressor rooms should be designed to offer every possibility of the operating force making a quick getaway if a rupture of any part of the compression system occurs.

A check valve installed in the discharge line is a very good safety precaution against the failure of a cylinder head or machine valve. Gas masks are too often in an inconvenient place. They are a most important part of any plant using toxic refrigerants. An occasional safety drill of the refrigeration plant personnel is recommended. This will indicate to all concerned the location of the several safety devices and emphasize any weakness in the planned safe practice procedure.

Liquid level gauge glasses except those of the bull's-eye or reflex type, should have automatic closing shut-off valves, and such glasses should be adequately protected against injury.

CODES FOR REFRIGERATION PLANTS

There are a number of codes and guides that should and must be followed in the construction and operation of a refrigeration plant. Local building codes and licensing should first be consulted to be sure that any new facility will conform with local ordinances so that it can be operated in compliance with local laws. Quite often the local codes will follow or copy exactly a recognized safety code. Where there is a conflict in codes, the local code will normally take precedence and should be followed. There are a number of recognized codes and guide lines that should be studied before construction of a facility. Most engineers and designers of plants are familiar with the following codes which should be reviewed periodically for changes and revisions.

OSHA

The Occupational Safety and Health Administration was created by the Federal Government to promote safety and prevent health hazards both during construction of a facility and in the operation of the completed facility. Copies of the rules and regulations pertaining to the particular facility being constructed or operated may be obtained from government offices and should be studied closely since, by law, they must be adhered to.

ASHRAE

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers publish a standard safety code for mechanical refrigeration which is very comprehensive and detailed concerning materials and construction procedures for refrigeration plants. Many communities use this code as a basis for local construction. Copies may be obtained from the offices of the ASHRAE in New York.

IIAR

The International Institute of Ammonia Refrigeration offers a number of charts for wall mounting and other printed matter pertaining to safety in the operation of ammonia plants. The Institute's offices are located in Chicago, Illinois.

CODES IN GENERAL

Codes normally set up a minimum safe standard for construction of plants and the components used in their construction. No part of a plant should ever be of less strength or dimensional standards than indicated in the code. In some instances, items exceeding code requirements may be desirable since most codes set out minimum safe requirements only.

GENERAL SAFETY PRECAUTIONS

It is well, in any plant utilizing mechanical equipment, that some of the personnel be trained in first aid procedures. Prompt action in emergencies by trained people can often save lives. An adequate supply of first aid supplies is also a requirement that should be adhered to diligently.

Types of refrigerant, machine room safety and ventilation, test pressures and electrical precautions are usually covered by existing codes and the owner and designer of a cold storage facility need to study these requirements prior to construction to be certain that violations are not built in to the plant design.

SOME SAFETY SUGGESTIONS FOR COLD STORAGE PLANTS

Plant Operation

(a) Combustible materials should not be kept in the plant except in proper containers and in all cases should be kept away from liquid refrigerant receivers.

(b) Forced air ventilation capable of rapid air change is extremely desirable in machine rooms.

(c) Rotating machinery and other equipment should be kept clean with no accumulated oil and grease. Good housekeeping should be a must in machine rooms.

(d) All electrical equipment should be properly grounded in accordance with existing electrical codes.

(e) Switchboards

   (1) All switchboards should be of dead front construction.

   (2) Current-carrying parts shall be enclosed with insulating material or grounded metal casings to prevent accidental contact and to prevent short circuits.

   (3) An insulating mat or insulated platform should be placed on the floor in front of the switchboard.

   (4) No energized conductors shall be touched or handled except by an authorized employee equipped with proper handling equipment.

   (5) Entrances to the rear of the switchboard shall be closed by gates. Warning signs forbidding the entrance of unauthorized persons shall be placed on the gates.

(f) More than one exit should be provided for a quick escape in case of emergency.

(g) A master control switch should be located in such a manner that, in case of emergency, the entire plant can be shut down without entering the building.

(h) Oil, gasoline or other gaseous liquids should not be used for cleaning purposes. Use only approved solvents and cleaners and in well ventilated areas.

Fire Prevention

(a) Store all inflammable liquids in approved enclosures.

(b) All tanks, containers and cans holding inflammable liquids shall be of approved design and suitably marked as to contents.

(c) Smoking and open flames should be prohibited where inflammable liquids are used or stored.

(d) Oily rags and waste should be kept in approved air-tight metal containers.

(e) In checking for flammable gas leaks, keep all flames away from area and check for leaks with soap suds or other plastic bubble type liquid. Take all precautions with flames until leak is found and repaired.

(f) Electric hand tools should always be properly grounded and used properly and with approved extension cords.

(g) Air compressor tanks should be drained at regular intervals. The use of non-flammable oil is recommended for air compressors.

(h) Fire extinguishers should be available at strategic points and of a type suitable for the equipment subject to burning. Instructions in their use should be given to plant personnel.

(i) Fire drills should be conducted at regular intervals to familiarize plant personnel with fire fighting equipment use.

Guards

(a) The following machines or machine parts shall be adequately guarded. (Follow OSHA requirements as well as insurance suggestions and state or local codes)

  (1) Belts, chains and all types of open drives.
  (2) Friction drives, gears and sprockets.
  (3) All types of exposed shafting.
  (4) Fly wheels, clutches, couplings and projecting shaft ends.
  (5) Emery wheels, motors or generators with exposed terminals and any rotating machinery where accidental contact could be made.

Repairs or Installations

(a) When repairs are to be made on a compressor, pump or any type of reciprocating or rotating machinery, a warning card - DANGER-MEN WORKING - should be attached to the starting device operating the equipment. In addition, the starting device should be locked in the open position when possible to prevent any starting of equipment while repairs are being made.

(b) Machinery should not be worked on or repaired while in motion except for speed regulation etc.

(c) When working on or in the crankcase of compressors, make sure that employees, tools, extension cords or other impediments are clear before turning compressor shaft. Also make sure all extraneous materials are removed from the interior of compressors before closing up the compressor and starting it.

(d) Follow instruction books and use only approved methods of repair and overhaul to prevent damage to equipment as well as personnel.
(e) Employees moving heavy equipment on rollers should not wear gloves and rollers should be of sufficient length to extend well past any equipment skids. (A glove finger can be caught under a roller and the hand pulled under the roller)

Tools

(a) The correct tool should always be selected for the job. Never use makeshift tools.
(b) The use of improper or unsafe tools should not be permitted.
(c) All chisels, bars, drills, etc., which are held by one worker and struck with any type heavy hammer by another should be held with long-handled tongs or other means to prevent a glancing blow or a missed blow from striking the employee holding the tool. Goggles should also be worn as well as face protection when possible.
(d) Tools whould be kept on tool boards, tool racks or in tool boxes when not in use.
(e) Select wrenches of the right size for the job. Face the jaws of an adjustable wrench in the direction of pull.
(f) All edged or pointed tools should be kept sharp. Dull tools are more dangerous than sharp ones.
(g) Avoid using a hammer with a hardened face on a highly tempered tool such as drill, file, die, jig, etc. Chips can fly with the speed of a bullet.
(h) Never use a wrench on moving machinery.
(i) Do not use an extension or "cheater" on a wrench. The proper length of a wrench handle is calculated and supplied by the manufacturer.

Ladders

(a) All ladders used in maintenance and construction shall conform to OSHA and other safety regulations.
(b) Employees should not be permitted to use a ladder that has cracked or boken rungs, side pieces or straps.
(c) Permanent ladders shall be built in accordance with OSHA requirements and local codes.
(d) Straight ladders should be of sufficient length that work may be reached when standing on the third or fourth rung from the rop.
(e) Step ladders should be of sufficient length that work may be reached from the second or third step from the top.

(f) The distance from the foot of a straight ladder to the wall should not exceed one-fourth of the distance from the floor to the top of the ladder.
(g) Ladders greater than 5 ft in length should be blocked or anchored or held by an assistant. All ladders should be equipped with nonslip shoes.
(h) Improvised ladders such as barrels, boxes, chairs, tables, etc., should not be used.

SAFETY DEVICES AND EQUIPMENT

Gas Masks

(a) Gas masks should be available in all plants where ammonia or any toxic gases are used for any purpose.
(b) Every plant employee should be instructed in the proper use of gas masks, whether air or canister type.
(c) Extra canisters and air tanks should be available for the type of mask used.
(d) Caution should be used in the use of air masks that the body is protected in high concentrations of gas so that burn or freezing injury does not occur.
(e) When using a canister type ammonia mask, if the odor of the gas becomes objectionably apparent, the employee should immediately leave the gas area. The canister should be replaced and mask examined before re-entering the area.

Goggles

(1) Employees using abrasive wheels or portable grinders should be required to wear goggles equipped with shatter proof lenses. They should also be required at all times when chipping or cutting concrete, breaking up junk, porcelain, handling, demolishing or cleaning brickwork, and on all classes of material or fluids affording possibilities of injury to the eyes.
(b) Goggles of suitably colored glass should be required when working with either gas or electric welders or any location exposed to excessive heat or glare.

Rubber Gloves

(a) Rubber gloves with gauntlet protectors should be easily accessible for use when working around live electrical parts and conductors.

Suitable Clothing

(a) Loose clothing should not be worn around moving machinery. Jumpers should be kept within overalls; keep sleeves down. Loose sleeves or trouser legs are also a hazard around machinery.

(b) Do not wear inflammable articles such as celluloid cap visors, celluloid eye glass frames, oily clothing, etc.

(c) Gloves shall not be worn around moving machinery.

(d) Avoid wearing metal articles, such as rings, watch or key chains, or metal cap visors.

(e) Keep good soles on shoes at all times. Shoes with thin soles will cause bruises and blisters and will allow the penetration of nails.

(f) Employees should wear safety shoes with safety toe caps. When working on ice or slippery surfaces, shoes with a special nonslip sole should be worn.

SAFETY IN DESIGN

The designer of each machine should incorporate safeguarding devices right into the machine. Too many machines must be provided with safety devices after they come from the manufacturer. It is very difficult to make satisfactory safety devices for a machine after it has been built.

Designers should visualize their design to see whether there is any part of their handiwork wherein an operator or repairman can be maimed for life by the crushing of a hand or finger in the moving parts which he must handle or repair frequently while the machine is in motion.

The temperature of bearings must be determined frequently, packing must be taken up and belts aligned. Provision should be made to do this with a minimum of hazard.

Projections from a machine may trip the operator. Ample aisle space should be provided so that there is no crowding of the machine operators into the danger zones.

Piping should be so designed that the expansion of the mains causes no undue strain at the compressor, condensers or evaporators. Very serious accidents have been caused by the rupture of a line or a valve at a point where the expansion pressure of the pipe has not been relieved by suitable provision of some kind.

SELECTED A.S.A. SAFETY INSTRUCTIONS ON INSTALLATION OF REFRIGERATION EQUIPMENT

Foundations and Supports for condensing units or compressor units shall be of substantial and noncombustible construction when more than 6 in. high.

Moving Machinery should be guarded in accordance with accepted safety standards.

Clear Space adequate for inspection and servicing of condensing units or compressor units shall be provided.

Condenser Units or Compressor Units with Enclosures shall be readily accessible for servicing and inspection.

Water Supply and Discharge Connections should be made in accordance with accepted safety and health standards.

Discharge water lines shall not be directly connected to the waste or sewer system. The waste or discharge from such equipment shall be over and above a trapped and vented plumbing fixture.

Illumination adequate for inspection and servicing of condensing units or compressor units should be provided.

Electrical Equipment and Wiring shall be installed in accordance with accepted safety standards.

Gas Fuel Devices and Equipment used with refrigerating systems shall be installed in accordance with accepted safety standards.

Machinery Room Requirements.—Each refrigerating machinery room shall be provided with tight-fitting door or doors and have no partitions or openings that will permit the passage of escaping refrigerant to other parts of the building.

Each refrigerating machinery room shall be provided with means for ventilation to the outer air. The ventilation shall consist of windows or door opening to the outer air, or of mechanical means capable of removing the air from the room. The amount of ventilation for refrigerant removal purposes shall be determined by the refrigerant content of the largest system in the machinery room.

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Appendix I

DEFINITIONS OF TERMS COMMONLY USED IN REFRIGERATION AND COLD STORAGE OPERATIONS

There are a number of terms peculiar to refrigeration systems, equipment and operation. Some of these terms have rather common usage in everyday language but have a different connotation when used in connection with refrigeration or cold storage work. Other terms are entirely generic to the refrigeration and cold storage industy. A number of these terms are listed in this appendix with definitions and explanations to clarify their meanings. Where numbers are used in the appendix, they will be expressed as whole numbers unless decimals or fractions are required for clarification of a term.

REFRIGERATION AND COLD STORAGE WAREHOUSE TERMINOLOGY AND DEFINITIONS

Absolute zero. The theoretical point on the temperature scale where a substance would have no molecular motion or heat. The temperature at this point is −460°F. or −273°C.

Absorbent. A substance, such as water, which is used to dissolve another substance, such as ammonia, to form a third substance; aqua ammonia.

Absorber. A closed vessel used in the absorption refrigeration system where the absorption process takes place.

Absorption. The process in which the absorbent is dissolving some other substance in the absorption refrigeration cycle.

Access door. A small door, usually gasketed or sealed, to gain access to machinery enclosed in a housing. Used for access to equipment for inspection as well as maintenance and repair.

Accumulator. A horizontal or vertical pressure vessel used in a refrigeration system to separate refrigerant liquid from vapor to prevent slop over of liquid refrigerant to the compressors; to temporarily store liquid refrigerant; to feed liquid refrigerant pumps or other circulating devices and to help smooth out pulsations in the refrigerant lines. Also known as a surge drum, particularly when used to feed flooded evaporators and prevent surges of refrigerant liquid from traveling to compressors.

Activated alumina. Aluminum oxide which readily adsorbs moisture. The property makes it useful as a confined drying agent in a refrigerant line.

Activated carbon. A special form of carbon of a porous nature which is capable of adsorbing various odors and vapors. Used in cold storage operations to adsorb some room odors.

Adiabatic process. A thermodynamic process, such as compression, in which no heat is added or extracted from the thermal system.

Adsorbent. A material, such as silica gel, which is used in refrigeration systems to catch and hold moisture and some acids which may be present in the refrigerant. The adsorbent holds moisture and other substances trapped in its structure but does not change physically or chemically. The adsorbent may be reactivated by removing it from the system and applying heat which will drive out the entrapped materials. The adsorbent is normally contained in a metal enclosure with appropriate filters.

Adsorption. The process of trapping moisture and other substances in the structure of the adsorbent.

Agitator. A propeller type device, driven by a power source, used to promote a liquid flow, or circulation, in a tank. An agitator can also be in the form of a pump drawing liquid from a tank and returning it to the tank in a manner that will promote liquid circulation within the tank.

Air, ambient. The air surrounding an object, such as a room. Also air surrounding an object, such as a coil, within a room.

Air, dry. Air containing zero water vapor.

Air, reheated. In some air conditioning processes, after air has been chilled to remove moisture, it is necessary to reheat the air to prevent too low a dry bulb temperature in the conditioned space.

Air, saturated. Air containing all the moisture it can hold. Relative humidity at this condition is 100% and it is impossible to evaporate any additional moisture into the air.

Air, standard. Air that weighs 0.075 lb per cu ft at 68°F. (20°C) dry bulb and 50% relative humidity at barometric pressure of 29.92 in of mercury.

Air blast. Forced air circulation at a rapid rate. Usually used in connection with freezing tunnels or other freezing methods.

Air changes. A method of expressing the amount of air leakage into or out of a building in terms of the number of air volumes of the room in a specified time. Also, in refrigerated areas, can refer to the number of air volumes corresponding to the room volume which pass through the cooling coil in a given time.

Air cleaner. A mechanical device used to remove airborne impurities by filtering. Used in heating and cooling systems.

Air conditioning. The simultaneous control of air temperature, humidity, cleanliness and movement in a designated area; either for cooling or heating as required.

Air cooler, forced circulation. A cooler where the air is forced over the cooling surfaces by means of a fan.

Air cooler, natural convection. A cooler where the air circulates over the cooling surfaces by gravity and without the use of fans. This type of cooler is rarely used in present day cooler design.

Air cooler unit. In its simplest form, a cooling coil with a circulating fan; built into a single enclosure. This is a basic refrigeration unit. For air conditioning, filters may be added as well as dampers and other devices.

Air diffuser. A mechanical device designed to mix conditioned air from a duct with ambient air to obtain a uniform air condition. Usually equipped with directional devices, either fixed or movable, to give a definite pattern to the resultant air stream.

Air filter. A mechanical device through which conditioned air passes to filter out airborne particles and some impurities.

Air washer. A containment, through which air passes, containing water sprays which can clean, humidify or dehumidify the air passing through the washer.

Algae. A minute fresh water plant growth which forms as a scum, or slime, on the surface of recirculated water apparatus, interfering with the water flow and heat transfer.

Anemometer. An instrument for measuring the velocity of air or other gas.

Approach. In an evaporative cooling device such as a cooling tower, the difference between the temperature of the water leaving the device and the wet bulb temperature of the entering air. Also used in refrigeration to designate the difference between the room air temperature and the temperature of the refrigerant inside the evaporator.

Atomize. To reduce a liquid to a very fine spray.

Automation. The design of a plant so that it will operate to maintain desired conditions entirely on its own control system without assistance of operators or other external means. Automated plants do require top-flight maintenance and cannot be neglected from this standpoint.

Azeotrope. The mixture of two chemicals to obtain a third chemical whose characteristics are entirely different from the chemicals from which it was made. The mixture is made in definite proportions and the resultant chemical is stable throughout the range in which it is used. Refrigerants 500 and 502 are both azeotropes.

Baffle. A partition, or partial partition, placed in an air stream or in any fluid flow to change or direct the direction of the substance.

Balance tank. A tank, either open or closed, placed in a circulating liquid system which balances the liquid flow and allows air to be expelled from the system. It also provides space for changes in volume due to termperature changes of the liquid.

Barometer. An instrument for measuring the atmospheric air pressure.

Bimetallic element. A device used to measure or control temperature and consisting of two different metals welded together, the two metals having different coefficients of expansion when subjected to temperature change. Application or removal of heat will cause the welded element to bend one way or the other. The bending motion is linked mechanically to an indicating needle or trip device to perform the function desired.

Blanch. To scald or sterilize (in the case of vegetables to be canned, cooked or frozen) by steaming or dipping in a hot-water bath at 212°F. (100°C).

Bleed-off. A small amount of water constantly drained from a cooling tower or other water evaporating equipment. The replacement of this water by fresh water tends to dilute scale forming impurities and solids in the water.

Blower. A fan, usually with housing, to force air under pressure for cooling or heating.

Boiler. A vessel for the production of steam or hot water with space enclosed for water and steam and provision for the application of heat.

Boiling point. The temperature at which a liquid vaporizes, or boils, with the application of heat.

Booster compressor. A refrigerant compressor used in the first or low stage of a two-stage refrigeration system. The compressor compressing the refrigerant gas from the system low pressure, or suction pressure, to the intermediate pressure, or suction pressure, of the high stage compressor.

Bore. The inside diameter of a compressor cylinder.

Braze. The joining of two metals together by the melting of a third metal, usually above 1000 deg. F. (538 C) but below the melting temperatures of the metals being joined. Common brazing metals are silver, brass and other similar alloys.

Brine. A circulating liquid used to refrigerate by the warming of the liquid rather than by evaporation. A brine may be any liquid or mixture of liquids having a relatively low freezing point. A brine may also be made by dissolving a solid into a liquid such as calcium chloride and water. Sometimes a liquid refrigerant may act as a brine when chilled below its normal boiling point for use in a brine circulating system.

Brine cooler; chiller. An evaporator for cooling brine in an indirect refrigeration system where the brine is cooled by the refrigerant and, in turn, circulated to the load or cold room where it removes the heat from the load by warming itself and then returns to the brine chiller for removal of heat.

Brine cooler net refrigerating effect. The cooling load of the brine chiller based on the quantity of brine per unit of time and the temperature range through which it is chilled.

Brine expansion tank. A vented vessel in a closed brine circulating system to compensate for expansion of the brine due to temperature change.

Brine return tank. A reservoir, in an open circulating brine system, for storage of brine at the pump suction.

Brine spray unit. A system in which cooling is achieved by a flow of air through a spray of cold brine, flowing over a refrigerated coil.

British thermal unit (Btu). The heat required to raise, or to be extracted to lower, the temperature of one pound of water 1°F.

Bypass. A pipe or duct, usually damper or valve controlled, for conveying a liquid or gas around an element in a system.

Calibration. The process of dividing and numbering the scale of an instrument; also of correcting or determining the error of an existing scale.

Calorie. The heat required to raise, or to be extracted to change the temperature of 1 gram of water 1°C.

Calorimeter. A device used in measuring heat quantities, or steam quality, or heat of combustion. Also used in determining specific heat and heat leakage.

Capacity, refrigerating system. The cooling effect of a refrigerant in a refrigeration cooling cycle and available for cooling at the evaporator. Measured in Btu per hour or in tons of refrigeration or in appropriate heat units for other measuring systems.

Capacity reducer. A device used on refrigeration compressors to reduce their effective gas pumping ability consisting of speed control, clearance pockets, cylinder bypass or other means. Used to balance compressor performance with load variations.

Capillary tube. A small bore tube used to meter refrigerant into an evaporator. Used instead of a thermal expansion valve. Used mostly in small domestic refrigerators and in residential air conditioning systems.

Carbon dioxide ice. Dry ice; a solid substance formed by snowing liquid carbon dioxide into a vessel at atmospheric pressure; then compressing the snow into a solid block. Temperature is −109°F. (−78°C).

Centrigrade. This scale also known as the Celsius temperature scale. A temperature scale in which the freezing point of water is 0°C. and the boiling point is 100°C. at normal atmospheric pressure.

Celsius temperature. See Centigrade.

Change of state. The change of a substance from a solid to a liquid or from a liquid to a vapor or the reverse.

Charge. The amount of refrigerant required to operate a complete system.

Chill. To apply refrigeration for the preservation of food stuff such as meats, eggs, produce and other items to be held above the freezing point.

Clearance. The space, in a reciprocating compressor, between the top of the piston and the cylinder when the piston is at the top of its stroke.

Clearance pocket. A space that may be opened into the cylinder of a reciprocating compressor to give the same effect as increasing the clearance of the piston. A device used to reduce compressor capacity to balance decreasing loads.

Coefficient of expansion. The change in length per unit length or the change in volume per unit volume per degree change in temperature.

Coefficient of heat transfer, overall. The rate of heat flow per unit area, under steady conditions, through a substance for a unit of temperature difference of the fluid on the two sides of the substance.

Coefficient of performance. The ratio of the refrigeration produced to the heat energy required to obtain the refrigeration. Power requirements of the system are expressed in heat units.

Coil, cooling. Piping or tubing, finned or plain, which transfers heat from air or other gas to a refrigerant or brine within the pipe or tubing.

Coil, direct expansion. A cooling coil containing a refrigerant metered to it by a hand; automatic or thermal expansion valve.

Coil, flooded. A cooling coil containing a refrigerant which is metered by a float valve or solenoid to keep the coil full of refrigerant. Used normally with a surge drum to prevent liquid slop over to the compressor.

Coil, recirculated. A cooling coil through which refrigerant is forced by a recirculating pump or other pressure device. The liquid refrigerant is circulated at several times the amount evaporated for refrigeration, thus assuring a wetted coil surface with an increase in heat transfer ability of the coil.

Cold storage. The storage, for extended periods, of food products at lowered temperatures but above freezing. In a broader sense, the term "cold storage" may also include freezer temperatures for storage of frozen products.

Compression. The process of compressing a volume of vapor into a smaller space. This raises the pressure of the vapor. Compression, in a refrigeration system is accomplished by the use of a reciprocating, screw, centrifugal or rotary type compressor.

Compression, heat of. Heat generated by the work done by a compressor in compressing a vapor from a low to a higher pressure.

Compression, multi-stage. Compression of a refrigerant gas in two or more steps, usually with the discharge of the low stage compressor discharging through appropriate intercoolers to the suction of a higher stage compressor.

Compression, ratio of. The ratio of absolute pressures after and before compression.

Compression, single stage. The compression of refrigerant vapor from evaporator (suction) pressure to condensing pressure in one step.

Compression, wet. A system in which some liquid remains in the refrigerant gas entering the suction of the compressor. In extreme cases, this can cause slugging of the compressor with valve breakage and other bad effects.

Compressor. A machine designed to compress a volume of vapor into a smaller volume, thus raising the pressure of the vapor. Common types of compressors used in refrigeration are reciprocating, screw, rotary and centrifugal.

Compressor, belt driven. An open type compressor with its flywheel fitted for belts and driven by an outside power source; power being transmitted through the belts from the driver to the compressor.

Compressor, booster. A compressor used in two stage compression to compress the first, or low stage from the evaporator pressure to the intermediate or middle pressure. This compressor is quite often of lighter construction than the high stage compressor.

Compressor, centrifugal. A nonpositive displacement compressor which depends for pressure rise, at least in part, on centrifugal effect. These compressors operate at relatively high speeds as compared to reciprocating compressors, pumping a relatively high volume of gas through a small pressure rise.

Compressor, compound. A compressor with more than one cylinder in which compression is accomplished by stages.

Compressor, direct connected. An open type compressor with its driving shaft connected directly with the driver through a coupling and operating at the same speed as the driver.

Compressor, double acting. A reciprocating compressor which has two compression strokes per revolution of the crankshaft per cylinder.

Compressor, hermetic. A motor compressor unit in which the compressor and electric driving motor are mounted on a common shaft and encased in a welded steel enclosure. Not accessible for servicing. The electric motor operates in the refrigerant atmosphere. Normally used in smaller sizes only.

Compressor, horizontal. A compressor with its cylinders operating in a horizontal plane.

Compressor, open type. A compressor with a shaft or other moving part extending through a casing to be driven by an outside source of power, thus requiring a stuffing box, shaft seals or equivalent rubbing contact between a fixed and moving part.

Compressor, positive displacement. A compressor in which increase in vapor pressure is attained by changing the internal volume of the compression chamber, such as a piston in a cylinder.

Compressor, reciprocating. A positive displacement compressor with a piston or pistons moving in a straight line inside of containing cylinders. The motion of the pistons being forward and back (reciprocating).

Compressor, rotary. A compressor in which compression is obtained by the rotation of an off center solid cylinder within a fixed cylinder. The solid cylinder is slotted with blades operating in the slots free to move in and out following the fixed cylinder walls. Gas trapped between the blades is forced out after being compressed. This type compressor is normally used for booster compression service with relatively low compression ratios.

Compressor, screw type. A compressor containing two helical lobes cut to mesh with each other and offering a continuous compression of vapor as it passes through the meshed lobes of the compressor. Variations of form of this compressor are offered by different manufacturers.

Compressor, single acting. A compressor having one compression stroke per revolution of the crank for each cylinder.

Compressor, vertical. A compressor with vertical cylinder, or cylinders.

Concentration. A number specifying the composition of a solution; such as pounds of salt per gallon of brine.

Condensate. The liquid formed by the change of state from a gas to a liquid.

Condensation. The process of changing a vapor (gas) into a liquid by the extraction of heat.

Condenser. A pressure vessel in which the vaporized (and compressed) refrigerant is liquified by the extraction of heat.

Condenser, air cooled refrigerant. A refrigerant condenser cooled by natural or forced circulation of atmospheric air. Usually constructed from finned type tubing.

Condenser, atmospheric refrigerant. A condenser with the cooling surfaces open to the atmosphere and cooled by a film of water flowing over those cooling surfaces. This type is now almost obsolete.

Condenser, closed shell and tube refrigerant. A condenser with closed water heads at each end, the heads being equipped with partition webs to direct the cooling water, under pressure, through the tubes in various combinations as required to obtain the desired water velocity in the tubes. The condensing refrigerant vapor is held in a shell through which the tubes pass and the liquid refrigerant drained out at the low point.

Condenser, double pipe refrigerant. A condenser consisting of a tube within a tube. The cooling water normally circulates through the inner tube with the condensing refrigerant vapor contained in the space between the larger outer tube and smaller inner water tube. Made in many shapes and forms.

Condenser, evaporative refrigerant. A condenser which combines, in essence, an atmospheric condenser with a forced draft cooling tower. The condenser tube bundle is placed inside a cooling tower housing with the sprayed water wetting the tubes in the tube bundle. Evaporation cools the spray water and the water extracts the heat from the refrigerant vapor inside the tubes and condenses it to a liquid.

Condenser, open shell and tube refrigerant. A condenser in which water passes in a film over the inner surfaces of the tubes which are open to the atmosphere. Similar in construction to a closed shell and tube condenser except without the water directing heads.

Condensing unit. Usually the complete high-side of a refrigeration system consisting of the compressor, condenser (air or water cooled) driving motor, receiver and controls all mounted on a common base so that the entire combination can be moved as a single unit. Constructed in a wide variety of sizes and configurations to fit many needs.

Conduction, thermal. The transfer of heat through a specified material.

Conductivity, thermal (k factor). The rate at which heat can be transmitted through a material. Expressed in heat units per hour through a unit area with a unit thickness per degree temperature difference.

Conservation of energy. A law of thermal dynamics that states that energy can be neither created nor destroyed.

Control. In cold storage and refrigeration, control usually refers to some type of temperature, pressure or other control used in conjunction with equipment either for operation or for safety.

Control, anticipating. A control actuated by some artificial means to make its response more sensitive and allow the control to operate at a closer differential than normal without the anticipator. Probably used most frequently on temperature sensing controls and in air conditioning installations.

Control, high pressure. A pressure device (usually an electric switch) actuated mechanically by fluctuations in high refrigerant pressure. The most common use of this device is as a safety to shut off equipment if pressures become too high.

Control, humidistat. An instrument sensitive to the moisture content of the air, mechanically linked to a switch to control various components of a system where humidity control is desired.

Control, low pressure. A pressure switch actuated by the suction pressure of a refrigerating compressor. Used to prevent too low a suction. Also used to actuate capacity controls to help maintain even pressures in a system.

Control, solid state. Any control employing solid state circuitry to accomplish electrical switching.

Control, thermostat. A temperature sensitive switch used to perform desired switching action on rise or fall in temperature.

Control, valve. Usually a solenoid valve actuated from a sensing control to open or close as desired. Also applies to motorized valves with slower acting characteristics and modulation.

Controlled atmosphere storage. A storage room, either refrigerated or not which is reasonably tight and into which is introduced a gas designed to perform certain functions such as ripening (bananas) and other types of air dilution. A storage room in which the composition of the air can be controlled.

Convection, forced or natural. Transfer of heat by the movement of a fluid such as air. Can be natural convection with fluid movement induced by changing temperatures, or forced convection as by a fan.

Cooler, chill. A cold storage room, usually above 32° F. (0°C) with sufficient cooling capacity to cool a product load such as fresh killed carcass beef plus the losses from the room. High humidity is also desirable for such a cooler.

Cooler, cold storage. A cold storage room designed to operate at temperatures above freezing for the storage, but not chilling, of perishable products.

Cooler, convertible. A cooler with sufficient insulation and cooling coils to permit it to be used either as a cooler or a freezer as required.

Cooler, tempering. A cooler room into which certain products may be stored temporarily to change their temperature or other characteristics without harm to the product. One example of this is a cooler arranged to warm products at low humidity to prevent sweating of a product as the dry bulb temperature is raised. Also a meat room in which frozen meat is allowed to thaw to bring it to a point where it is easily worked with slicers and other equipment for packaging, etc.

Cooler, special purpose. Any cooler, as the tempering cooler, designed to accomplish a specialized cooling operation not possible in a standard cold storage cooler.

Cooler unit. A manufactured assembly usually including a cooling coil, fan (direct connected or belted to an electric motor) and associated controls, for installation in the space to be cooled.

Cooling tower. A device for bringing a quantity of circulating water into intimate contact with the air to cool the water by its own evaporation.

Cooling tower, atmospheric. A cooling tower consisting of an interior space, either empty or with decking. The sides of the tower are louvered to permit free air circulation. Water pumped to the top of the tower is either sprayed down or caused to flow over the decks. The water movement as well as temperature changes from evaporation cause a natural draft to exist. The water, cooled by evaporation is pumped from the bottom, or pan, of the tower.

Cooling tower, forced draft. A cooling tower in which the water is sprayed or flowed over wetted decks, as in an atmospheric tower, except that air is forced into the tower mechanically by means of a driven fan for positive air circulation. Eliminator sections on the air leaving side prevent excess water from being blown from the tower.

Cooling tower, induced draft. A cooling tower similar to the forced draft tower in interior construction except that the air is mechanically pulled through the tower instead of being forced through. This is also done mechanically by a driven fan. The water eliminator section is placed just before the fan section to prevent excess water loss.

Cooling tower drift. Free water that escapes the eliminator plates in fan type cooling towers or that is blown out of atmospheric towers by medium and high wind pressure.

Cooling water. Normally cooling water refers to any water used to condense a refrigerant, cool a compressor jacket or other function in a refrigeration plant. The source of this water may be from a cooling tower, a river or lake, city water, well or other non refrigerated source.

Copper plating. A condition in which a copper like plating may be deposited on interior parts of a halocarbon compressor. Caused by impurities present the refrigerant. A properly cleaned system will not show copper plating.

Cork board. For many years cork board was used as a standard for insulating values and still is to some extent although the material itself has largely been replaced by newer insulants.

Corrosive. Having a rusting or destructive effect on a metal, such as acid eroding iron. Anything that tends to deteriorate the composition of a metal or other material over a time period.

Counterflow. A method of heat transfer where the coldest portion of one fluid meets the coldest portion of another in the exchange of heat between the two.

Critical point. A point in pressure and temperature of a substance where the characteristics of the vapor and liquid are the same.

Cryogen. A very low temperature refrigerant. Included in these are liquid nitrogen, helium and other extreme low temperature gases.

Cryogenics. The science, or art, of very low temperature refrigeration.

Cutting room. A cooled room in which animal carcasses are cut up in commercial sizes, roasts, steaks, etc.

Cycle. A complete operation, such as a refrigeration cycle where a refrigerant is evaporated, compressed, condensed to a liquid ready to start the evaporation over again. A complete operation, thermo-dynamically.

Cycle, closed. Any cycle in which the primary medium is always enclosed and repeats the same sequence of events.

Cycle, defrost. A period in a refrigeration cycle, where refrigerant temperatures are below freezing, that the cycle is interrupted to remove accumulated frost from the coil or refrigerated surface. This is done by the application of heat by above freezing temperature air, water, electric heat or internal heat from hot refrigerant gas.

Cycle, refrigeration. The complete thermodynamic process in a refrigeration plant to produce the desired refrigeration effect.

Dalton's law of partial pressures. In a mixture of two gases that do not change chemically, each gas acts as if it were acting alone under its own pressure and the total pressure of the mixture is the sum of the pressures of the individual gases.

Damper. A valve, or plate, used to regulate the flow of air or other fluid.

Decibel. A unit commonly used for expressing sound or noise intensities referred to an arbitrary reference level.

Defrost, air. Defrosting a refrigerated coil by forcing air at above freezing temperature over the refrigerated surface to remove accumulated frost.

Defrost, electric. Defrosting a refrigerated coil by heat supplied from an electric heater. The heater is usually built into the coil unit as a permanent part.

Defrost, hot gas. Defrosting a refrigerated coil by introducing hot gas from the discharge of the compressor into the coil and utilizing the heat of the gas as well as the latent heat to remove the accumulated frost on the external surface of the coil.

Defrost, water. Defrosting a refrigerated coil by flooding or spraying water over the surface, melting the accumulated frost and ice.

Degree day. A unit determining the amount of heating required over a given period of time; equal, for any one day, to the difference between an arbitrary base temperature of 65°F. (18°C) and the average outside air temperature over that 24 hour period.

Dehumidification. The condensation of water vapor from air by cooling below the dew point or the removal of water vapor from the air by chemical or physical means.

Dehumidifier. An air cooler or washer used for lowering the moisture content of the air passing through it. An absorption or adsorption device for removing moisture from air.

Dehydration. The removal of water, particularly in stored foods, when not stored properly to prevent the removal. Also the removal of water vapor from air by the use of absorbing or adsorbing materials.

Density. The mass or weight of a substance per unit of volume.

Desiccant. Any absorbent or adsorbent liquid or solid that will remove water or water vapor from a material.

Desiccation. Any process of evaporating water or removing water vapor from a material.

Design pressure. The maximum allowable pressure, or working pressure, for which a specific part of a system is designed.

Dewpoint. The temperature at which the moisture will start to condense out of air under constant pressure.

Diesel engine. An internal combustion engine using the heat of compression to ignite the fuel rather than an electric spark.

Differential (control). The difference between cut-in and cut-out points of a control.

Discharge line. In a refrigeration system, the line from the compressor discharge to the condenser.

Diffuser, air. An air delivery device, used in air conditioning and cooling, to promote mixing of the primary (cooled or heated) air leaving the diffuser with secondary (room) air by aspirating action. Also to give direction or a pattern to the air circulation.

Diffuser, refrigerant. A device, sometimes used at the end of a pressure relief line, to help diffuse refrigerant into the air in case of the operation of a pressure relief device.

Displacement. Volume swept by a piston per revolution of the crankshaft in a reciprocating compressor.

Displacement, actual. The actual volume, at compressor inlet conditions, of gas moved per unit of time.

Displacement, theoretical. The total volume displaced by all the pistons of a compressor at a given rpm per unit of time.

Distributor. A device for dividing the flow of liquid between parallel paths in an evaporator or other type of heat transfer apparatus.

Drier. A manufactured device containing a desiccant, placed in the refrigerant circuit; its primary purpose being to collect and hold moisture and some other impurities.

Dry ice. Solid carbon dioxide, CO_2 (proprietary term)

Duct. A passageway made of sheet metal or other suitable material for conveying air or other gas at low pressure.

Dunnage. Strips of wood or other material used in storage rooms to provide air space between the floor and packages and also between packages of products.

Dynamometer. A device for measuring the power developed by an engine or motor or other power producing driver.

Efficiency, mechanical. The ratio of the compression energy, or work done by the compression, to the energy input to the compressor.

Efficiency, volumetric. Ratio of the actual volume of gas moved by a compressor to the actual displacement of the compressor.

Electrical precipitator. A device for removing dust from the air by means of electrical charges induced on the dust particles.

Electrostatic air cleaner. A package air cleaner for removing dust particles from the air utilizing electric precipitation.

Emissivity. Characteristic of a surface for giving off heat by radiation.

Energy available. The portion of the total energy that can be converted to work in a perfect engine.

Enthalpy. A term used in thermodynamics to express various heat equivalents, or quantities.

Entropy. A relationship between heat and temperature. Used in refrigeration cycles to determine discharge temperature after compression. Also useful in prediction of other temperatures.

Equalizer. Usually refers to a piping system or arrangement to provide equal pressures between different vessels, or between different points in a system.

Eutectic mixture (solution). A mixture which melts or freezes at constant temperature and with a constant composition. The melting point of the mixture is usually the lowest for mixtures of given substances.

Evaporation. The change of state from a liquid to a vapor.

Evaporative cooling. The adiabatic exchange of heat between air and a water spray or wetted surface. The water assumes the wet bulb temperature of the air, which remains constant during its traverse of the exchanger.

Evaporator. In a refrigerant cycle, the cooling surface inside of which the refrigerant is evaporated at a controlled pressure to absorb heat from the air or substance being refrigerated; a part of the low side of the refrigerant cycle.

Exhaust opening. An opening through which air is removed from a space being heated or cooled, humidified or dehumidified or ventilated.

Expansion, dry. A refrigeration coil or evaporator into which refrigerant is metered in such a manner that all of the liquid is evaporated by the time it reaches the outlet connection and the gas returning to the compressor through the suction line is dry and contains no liquid.

Expansion joint. In refrigeration piping, a joint in the piping containing a bellows-like joint or a pipe loop to absorb any linear motion caused by changing temperatures in the piping or motion in the supporting structure.

Extended surface. A heat transfer surface on which one or both sides have their surface increased by the addition of fins, discs or other means.

Expansion tank. A vessel, or tank, in a water or other liquid circulating system to store excess liquid and also to store and feed liquid volume difference in the system due to changing temperature.

Factor of safety. The ratio of the ultimate stress of a material to design working point.

Fahrenheit. A temperature scale in which 32° is the freezing point of water and 212° is the boiling point at sea level and under normal atmospheric pressure.

Fan. A complete assembly of an air moving piece of equipment, usually consisting of a rotor, housing and drive. The term may designate a blower or exhauster.

Fan, centrifugal. A fan rotor or wheel within a scroll type housing and including driving mechanism supports for belt drive or direct connection.

Fan, propeller. A propeller or disc-type wheel within a mounting ring and including driving mechanism supports for either belt or direct drive.

Fan, Tubeaxial. A propeller or disc type wheel within a cylinder and including driving mechanism supports for either belt or direct drive.

Fan, vaneaxial. A disc type wheel within a cylinder with a set of air guide vanes located either before or after the wheel and including driving mechanism supports for belt drive or direct connection.

Filter. A device for removing solid material from a fluid.

Fin. An extended surface such as metal sheets attached to tubes and used to extend, or increase, the surface of a tube and increase its heat transfer ability.

First law of thermodynamics. A law stating the principle of the conservation of energy, equating heat and mechanical energy and denying perpetual motion.

Flammable refrigerant. Any refrigerant that will burn when mixed with air, such as ethyl chloride, methyl chloride and the hydrocarbons.

Flash chamber. A separating tank placed between the expansion valve and the evaporator in a refrigeration system to by-pass any flash gas around the evaporator.

Flash gas. The refrigerant gas, or vapor, resulting from the very rapid evaporation of refrigerant in a pressure reducing device, such as an expansion valve.

Flash point. The temperature of a combustible material, such as oil, at which there is sufficient vaporization to ignite the vapor, but not sufficient vaporization to support combustion of the material.

Fluid. Any gas, liquid or vapor; hence, a material that flows other than solids such as sand, etc.

Fluid, primary. The refrigerant of the primary system that can be found in a vapor state as well as in a liquid state in different parts of the system.

Fluid, secondary. Normally a liquid that does not change state under the conditions of a secondary refrigerant and also usually cooled by the primary fluid or refrigerant.

Foaming. The formation of a foam or froth of oil-refrigerant due to the rapid boiling of the refrigerant dissolved in oil when the pressure is reduced suddenly.

Fog. Suspended liquid droplets generated by condensation from a vapor or gas to the liquid state; or by the breaking up of a liquid into small droplets by splashing, foaming or atomizing.

Foul gas. Extraneous gases in a refrigeration system formed from the breakdown of refrigerant or oil or from moisture and other gases not belonging to the refrigerant. These gases cause high head pressures and can also cause corrosion of some of the interior parts of the refrigeration system.

Free area. The total minimum area of the openings in a grille, face, or register through which air can pass.

Freezer. Any storage room kept at some temperature below freezing.

Freezer, blast. A freezing system in which large quantities of air are circulated over cooling coils and over the product to be frozen at high velocities. Temperatures as low as −40°F (−40°C) are used in this process.

Freezer, combination. A normal holding freezer in which unfrozen products are sometimes frozen. Not usually considered good practice.

Freezer, holding. A freezer room in which frozen products are held in storage until needed for distribution. Normal temperature range of this freezer is from 0°F (−18°C) to −10°F (−23°C).

Freezer, special purpose. A freezer designed to hold products at some temperature other than standard, or where close limits in temperature must be observed or where special configuration of the room to some process or storage arrangement must be used.

Freezer, tunnel. An adoption of a blast freezer in which the product is placed on some type of rack or conveyor within a relatively small space with air directed at high velocity over the product for rapid freezing. Flow of product in a tunnel freezer can be continuous or in batches.

Freezer, storage. A general term used to indicate a cold room at freezer temperature. Synonymous with holding freezer.

Freezing point. The temperature at which a given liquid substance will change to a solid state, or freeze, upon removal of heat.

Freezing time. The time to freeze a product from the time it enters a freezer until the center of the package is frozen.

Frost back. The flooding of liquid refrigerant from an evaporator into the suction line to the compressor.

Gas. Usually a highly superheated vapor which, within certain limits, satisfies the perfect gas laws.

Gas, inert. A gas that neither experiences nor causes chemical reaction nor undergoes a change of state in a system or process.

Gas, non condensible. A gas in a refrigeration system that does not condense at the temperature and partial pressure at which it exists in the condenser, and therefore imposes a higher head pressure on the system.

Gauge (Gage). An instrument for measuring pressure or liquid level. Also used in the sense of an arbitrary measurement of sheet metal thickness, wire and drill diameters, etc.

Gauge glass. A glass or plastic tube used to indicate liquid levels.

Glazing. The addition of water to a frozen product to form a glaze of ice, thus reducing the possible desiccation of the product while it is in storage.

Grille. The lattice or grating of a delivery or intake opening usually for air passage. Also shaped to give an air flow pattern and direction in delivery-grilles.

Halide torch. A halocarbon refrigerant leak detector utilizing a flame over a copper reactor plate. Under the influence of a halogen gas, the flame will turn from blue to green or yellowish green. The flame is usually fed by alcohol, propane or acetylene.

Halocarbon refrigerants. A group of man-made chemicals that are used as refrigerants.

Head, dynamic or total. In a flowing fluid, the sum of the static and velocity heads at the point of measurement.

Head, static. The static pressure of a fluid expressed in terms of the height of a column of fluid. Also may be expressed in pressure increments such as psi.

Head, velocity. The pressure of a fluid due to its velocity through a channeling or pipe system.

Heat. A form of energy that is transferred by virtue of a temperature difference.

Heat, latent. The heat quantity required to effect a change of state in a solid, fluid or vapor.

Heat, sensible. The heat required to effect a change of temperature in a solid, liquid or vapor (gas).

Heat, specific. The ratio of the quantity of heat required to raise the temperature of a given mass of any substance 1° to the quantity required to raise the temperature of an equal mass of a standard substance, usually water, 1°.

Heat, total. An old term, now discarded in favor of the term "enthalpy."

Heat exchanger. A device specifically designed to transfer heat between two physically separated fluids.

Heat of fusion. The latent heat involved in changing from a liquid to a solid state.

Heat of the liquid. The enthalpy of a liquid above an arbitrary zero point.

Heat of vaporization. The latent heat required to change a liquid to a vapor.

Heat pump. An air conditioning or industrial system where the refrigeration cycle is used for both heating and cooling. In a simplified form, for cooling, the cycle is used normally with the conditioned air being cooled by the evaporator coil and the heat of the system rejected by the condenser. For heating, the conditioned air is blown over the condenser and heated while the former condenser acts as an evaporator and cools outside air to load the system.

Heat rejection, compression cycle. That portion of the heat absorbed by the evaporator plus the heat of compression of the compressor, all of which is removed by the condenser.

Heat transmission. The rate at which heat will flow through an obstruction per degree temperature difference between the two sizes. Materials with a high degree of resistance to heat flow are called insulants.

High side. That part of the compression refrigeration system that is operated at high, or condensing pressure.

Hold over. A tank in which are placed evaporator surfaces on which a substance such as ice may be frozen during off refrigeration peaks of the plant. During heavy usage, the ice is melted to produce cooling to aid the refrigeration plant as an auxiliary source.

Horsepower. A unit of power equivalent to the work done at the rate of 550 foot pounds per second or 33000 foot pounds per minute. One horsepower of work is accomplished if 33000 pounds is raised one foot in one minute or 550 pounds raised one foot in one second.

Hot gas line. The discharge line of a compressor to the condenser. Also a line from the compressor discharge to a cooling coil for use during hot gas defrosting.

Humidifier. A device to add humidity to the air stream by a fine spray or by presenting a wet surface to the air or by the introduction of steam into the air. May be operated with a separate fan to move the air through the humidifier or placed in the moving air stream of a system.

Humidify. The act of adding humidity to the air.

Humidity, absolute. The weight of water vapor per unit volume of air.

Humidity, relative. The relative amount of water vapor in the air compared to the amount that would be present if the air were fully saturated. Expressed as a percentage.

Humidity, specific. The weight of water vapor (steam) associated with a unit weight of dry air.

Hydrometer. A floating instrument calibrated to show the specific gravity of a fluid by the submergence of the hydrometer.

Hygrometer. An instrument responsive to the humidity conditions in a space and calibrated to read relative humidity.

Hygroscopic. A substance which will readily absorb moisture and also retain the absorbed moisture.

Hygrostat. An automatic control responsive to humidity.

I.Q.F. Initials standing for "individually quick frozen." A patented process used to freeze products individually in an air blast rather than in a package or closed container.

Ice Bank. An ice accumulating system where ice is formed on surfaces in a tank during periods of little use of refrigeration and the refrigeration obtained from melting the ice used during high peak periods. Useful in dairies, air conditioning and other refrigeration loads requiring high capacity for relatively short periods.

Ice melting equivalent. The amount of heat absorbed by 1 lb of ice at 32° F. (0° C) in liquifying to water at the same temperature. A figure of 144 Btu (36.3 kgm cal) is normally used for this heat quantity.

Immersion freezing. A method of freezing where the product to be frozen is immersed in a very cold liquid. Very rapid freezing is accomplished by the intimate contact of product and cold liquid.

Inch of water. A unit of pressure equal to the pressure exerted by a column of liquid water 1 in high at a temperature of 39.2° F. (4° C).

Industrial air conditioning. Air conditioning in work spaces and factories. Also specialized cooling for working products where temperature and/or humidity must be controlled. Control of this type air conditioning is often more critical than for comfort air conditioning.

Infiltration. Air flowing inward to a conditioned space, as through the pores in a wall or through cracks around doors and windows.

Insulation. A barrier erected to the flow of heat.

Insulation, foamed. An insulant, such as polyurethane, formed by foaming two chemical agents together to produce an effective insulation. May be foamed in place or foamed in blocks and cut into appropriate shapes as required.

Insulation, loose fill. Granulated fibrous, shredded or powdered material prepared from vegetable, mineral or animal origin, prepared in bulk or batt form to supply a barrier to the flow of heat. Normally installed between supporting surfaces, such as a double stud wall.

Insulation, preformed. Insulating covers for fittings and valves, mold formed or carved from rigid insulation to make an exact fit. Also formed insulation to fit over pipe runs.

Insulation, rigid. Insulation in board form made up in a composition to give some structural strength. Materials include corkboard, polyurethane, styrofoam, beadboard, and other rigid board forms.

Insulation, sound. The acoustical treatment of housings, ducts and systems for isolation of vibration, or to reduce transmission of noise.

Intercooling. The removal of heat from a compressed gas between stages of compression.

Internal combustion engine. A piston engine deriving its power from the rapid burning of a fuel-air mixture in the cylinder ignited either by a spark or compression pressure developed temperature. The rapid burning causes expansion of the gases within the cylinder and driving the piston to produce power through a crankshaft.

Interstellar cooling (sky cooling). Radiation, especially on clear nights, from an exposed surface to the cold upper air strata.

Irradiation. The subjecting of foods, etc., to radiation wave lengths which destroy certain bacteria.

Isentropic. A reversible adiabatic process; a change taking place without loss or gain of energy.

Isothermal. A change taking place at constant temperature.

Jacket water. Water used for cooling the cylinder head and/or cylinder walls of a compressor.

Joint, brazed. A pipe joint secured by brazing with a brazing rod and heat; the rod melting at lower temperature than the joined metals.

Joint, mechanical. A pipe joint made up with threads and mechanically screwed together.

Joint, soldered. A pipe joint made up with low temperature solder such as a lead-tin mixture melted into the joint for a holding seal.

Joint, welded. A joint made up of pipes welded together by fusion of the pipe metals from heat.

Joule-Thomson effect. The fall in temperature which occurs when gas is allowed to expand without doing external work.

Leak detector. A device used to detect leaks in a refrigerant system.

Liquid indicator. A device, also called a sight glass, placed in a liquid refrigerant line showing liquid flow through a transparent window in the device. Also sometimes refers to liquid bullseyes placed in a receiver or pressure vessel to show whether liquid is present.

Liquid line. The line from the refrigerant receiver to the expansion valve or other pressure reducing device at the evaporator.

Liquefaction. The change of state from a gas to a liquid. This term generally used instead of condensation when referring to substances ordinarily found in a gaseous state, such as nitrogen.

Load. In refrigeration, the heat load imposed on the refrigeration system. The amount of heat removed by refrigeration.

Load factor. The ratio of actual mean load to a maximum load or maximum production capacity for a given period.

Log sheet. A data sheet filled out at set intervals giving pertinent information on pressures and temperatures, operating times, equipment in use and other data required to give a complete picture of plant performance required for efficient operation.

Low side. The evaporator and suction piping, accumulators and other equipment operating under the evaporator pressure in a refrigeration plant.

Machine room. An equipment room in a refrigeration plant utilizing a central machine room instead of isolated units. Normally contains compressors and drives, condensers, various accumulators, pumps and other related equipment confined to a single area.

Make-up water. Water supplied to a cooling tower or evaporative condenser to replace water evaporated in the cooling process, water lost by drift and water bled from the device to reduce the solid content of the water.

Manometer. A U-tube or single tube and reservoir, used with mercury or other suitable liquid to measure pressure differences.

Mechanical equivalent of heat. An energy conversion ratio of 778 ft lb = 1 btu.

Metabolism. The chemical changes in living cells by which energy is provided for vital processes.

Miscible. Liquids that will mix or dissolve in each other.

Modulation (of a control). An automatic adjustment of a control in small increments giving a smooth cycle of control instead of on-off characteristics.

Moisture indicator. A device placed in the liquid line of a refrigeration plant, usually in combination with a sight glass, which indicates the amount of moisture present in a system by the color of the device; the color changing as moisture content changes.

Oil separator. A device for separating oil and oil vapor from the refrigerant, usually installed in the compressor discharge line.

Open system. A circulating brine or water system in which the circulated fluid is stored in an open tank with pumps circulating the fluid through the coils or other loads and the fluid then returning to the open tank by pump pressure and gravity. Used in ice accumulator tanks or other systems where it is impractical to chill the fluid in a closed circuit.

Packing. A metallic, semi-metallic or fibrous material usually in rings, placed in the annular space between a rotating shaft and the compressor housing with a means of compressing the packing to form a gas and liquid type seal around the rotating shaft.

Packing plant. An establishment engaged in the slaughtering, dressing and processing of animals for food. Also an establishment concerned with the preparation of vegetables, fruits, fish and food products in general.

Pallet. A wood or composition platform on which are stored various packages of food stuffs and other commodities. The pallet is so arranged that it has slots for fork-lift trucks so that a complete pallet load may be easily transported and stacked for storage.

Partial pressure. When two gases occupy a vessel and do not mix chemically; each vapor acts as if it were under its own pressure, this partial pressure being determined by the proportionate mix of the gases. The sum of the partial pressures equals the total pressure on the vessel.

Performance factor. In a mechanicl condensing unit, the ratio of the capacity of the unit to the energy input, both expressed in equal terms.

Phase. In thermodynamics, one of the states of matter such as solid, liquid or gas. When used in connection with electrical circuits, the type of current supplied such as single or three phase.

Pipeline refrigeration. A system of refrigeration with a large capacity central plant and circulating either refrigerant or chilled brine to several separate buildings or complexes remote from the central plant, the lines usually buried or running in tunnels beneath the ground.

Plenum. A chamber, under pressure, receiving air, or other gas and usually from a single source. The air accumulation is then distributed through multiple ducts to various points of distribution.

Potentiometer. An instrument for measuring or comparing small electrical forces.

psi. Pounds per square inch.

psia. Pounds per square inch, absolute.

psig. Pounds per square inch, gauge.

Power. The rate of doing work.

Precooler. A vessel used to partially cool a fluid in advance of the regular refrigeration cycle. Also a cooler used to cool vegetables and fruits prior to shipment.

Pressure, absolute. The total pressure measured above absolute zero pressure. Also expressed as gauge pressure plus atmospheric pressure.

Pressure, atmospheric. The pressure exerted by the atmosphere, or air, above the surface of the earth.

Pressure, back or suction. The operating pressure in a refrigerating plant, measured in the suction line at the compressor inlet.

Pressure, critical. The vapor pressure corresponding to the critical temperature. The point at which the liquid and the vapor have the same characteristics.

Pressure drop. The loss in pressure due to friction of a fluid in a pipeline measured between two points in the line of flow.

Pressure, dynamic. The sum of the static and velocity pressures at the point of measurement.

Pressure, gauge. The pressure above atmosphere. This is usually the pressure read at various points in a refrigeration plant by the normal Bourbon tube type pressure gauge.

Pressure, head (discharge). The pressure in a refrigerating plant measured in the discharge line from the compressor.

Pressure, saturation. The pressure at which vapor and liquid, or vapor and solid can exist together in a stable condition.

Pressure, total. The sum of the static pressure and velocity pressure at the point of measurement.

Pressure, vapor. The pressure exerted by a vapor.

Pressure vessel. A closed tank constructed to withstand, with safety, the pressure exerted by the fluid for which it was designed.

Primary fluid. Normally, the refrigerant used in a refrigeration system. This nomenclature will usually be found where a brine, or secondary refrigerant is being used, chilled by the primary refrigerant of the refrigeration cycle.

Psychrometer. An instrument used to ascertain wet and dry bulb temperatures. From these readings, the relative humidity and dew point of the air may be obtained.

Psychrometric charts. A graphical representation of the properties of air and water vapor.

Pump, centrifugal. A fluid circulating pump that circulates the fluid by exerting centrifugal force on the fluid, causing it to flow. A non-positive flow pump. Restricting the discharge of the pump does not build up the power to operate the pump, the highest horsepower required being that of unrestricted flow.

Pump, positive displacement. A pump, such as a piston type where the rotation or movement of the pump parts cause a positive fluid flow. Restriction of the pump discharge causes increased load on the driver. Complete blockage can sometimes cause breakage.

Pump, refrigerant. A pump of any type which is sealed against leakage and used for the purpose of pumping a liquid refrigerant, as in a recirculating refrigerant system or for transferring liquid refrigerant from one part of the system to another.

Pump down (refrigeration system). A refrigeration system where, when the load is satisfied, the liquid refrigerant is trapped in the receiver and the compressor shut down by low pressure; on start-up, the refrigerant is released to the refrigeration system and the build up of pressure starts the compressor. The term is also used when storing the refrigerant in the receiver by manual control when repairs to the system are to be made.

Pump out line. A utility line connecting various parts of a refrigeration system through which the refrigerant gas may be pumped to remove refrigerant from a desired section.

Purger. A device for removing non-condensible gases from a refrigeration system. May be either manual or automatic in operation.

Pyrometer. An instrument for measuring temperature.

Quick frozen. A reference to any of several processes designed to freeze food stuffs quickly for preserving both texture and flavor.

Range (cooling range). The range, or number of degrees cooling of a fluid in a refrigeration system. The quantity of fluid per unit of time and the cooling range determine the load of the system.

Receiver. A pressure vessel normally placed after the condenser in a refrigeration system to receive the condensed liquid refrigerant and also to store the refrigerant until needed. Receivers may also be placed in some low side positions in a refrigeration cycle for specialized use.

Refrigerant. The medium of heat transfer in a refrigerating system which picks up heat by evaporating, or boiling, at a relatively low temperature and pressure and gives up heat on condensing at a higher temperature and pressure.

Refrigerant, secondary. Normally a refrigerant that does not change state in its normal operating range as a secondary refrigerant but cools by absorbing heat that raises the temperature of the secondary refrigerant (fluid). Chilling of the secondary refrigerant is usually done by evaporation of the primary refrigerant.

Refrigeration. The process of extracting heat from a substance or space, by any means.

Refrigeration cycle. The complete cycle of refrigeration, in a compression refrigeration system, from evaporation to compression to condensation to the receiver and back to evaporation. A complete cycle.

Regain of moisture. The amount of moisture absorbed by any material or substance in percentage of the weight of that material.

Register. A grille in combination with a control damper. Used primarily in air conditioning air distribution systems.

Respiration (of fruits and vegetables). The production of CO_2 and heat from the ripening and "breathing" of perishables in storage.

Rupture member. A metal disc fastened in an outlet from a refrigeration system designed to break, or rupture if the system pressure exceeds the disc design pressure. A safety device. The disc allows the refrigerant to escape before pressure can be built to a dangerous level.

Safety head. The head of a cylinder, in a reciprocating compressor, held down by a strong spring. Under conditions of liquid slugging of the compressor, the spring will allow the head to lift and the liquid escape to the compressor discharge without compressor damage. Effective in wet gas situations but not always effective in the case of solid liquid entering the head.

Salinometer. A hydrometer calibrated in terms of salt concentration.

Saponify. To turn to soap.

Saturated air. Air holding all of the water vapor it can hold; any additional moisture will cause a rain.

Seal, shaft. A metal to carbon or other rubbing combinations to seal off a rotating shaft and fixed housing from leaks to the atmosphere.

SI units. A system of International units of measurement.

Sight glass. See liquid indicator.

Silica gel. A drier material having the ability to adsorb and hold moisture having the basic formula, SiO_2. A sand like substance.

Slop over. Also called "frost back." An excess of liquid refrigerant return from the evaporator in a refrigerant system.

Slugging. Slop over in a dangerous form in that the excess liquid enters the compressor suction. In an aggravated form this can cause compressor damage.

Specific gravity. The density of a material compared to the density of a standard, usually water expressed as a decimal of a unit weight.

Specific volume. The volume of a substance per unit of weight.

Spray pond. An arrangement of sprays of water falling into a collecting pond for the purpose of lowering the temperature of the water by evaporative cooling of the water in contact with the outside air.

Standard conditions. Operating conditions specified by codes under which standard ratings are obtained which will be uniform for all equipment.

Starved evaporator. In a refrigeration system, an underfed evaporator; hence an evaporator that is not performing at its full efficiency.

Steam. Normally refers to water vapor at a temperature of over 212°F. (100°C).

Strainer. A contained fine mesh screen placed in a fluid line to mechanically remove solids from the flow of the fluid.

Stroke. The travel of a piston in a reciprocating compressor.

Stuffing box. The area in a reciprocating compressor where the drive shaft emerges from the casting. The seal between the compressor and rotating shaft.

Subcooling. The cooling of a refrigerant below condensing temperature for a given pressure.

Sublimation. A change of state directly from a solid to a gas.

Suction line. The piping between the evaporator in a refrigeration plant and the compressor inlet.

Sun effect. Solar energy transmitted through windows and building materials.

Superheated vapor or gas. Vapor at a temperature which is higher than the saturation temperature (boiling point) at the existing pressure.

Surge drum. A closed vessel placed in a refrigeration system to trap out liquid refrigerant that might otherwise be carried to the compressors in the form of slugs.

System, absorption. A refrigerating system in which the refrigerant gas from the evaporator is taken up in the absorber and released in a generator upon the application of heat and at higher pressure. The released gas is then condensed and returned to the evaporator.

System, cascade. A refrigeration system normally used for very low temperatures in which the compressed vapor from the low temperature system is condensed by the evaporator of the higher temperature refrigeration system, the two systems using different refrigerants and being isolated from each other.

System, central plant. A refrigerating system in which all of the equipment except the evaporators and some piping is confined to a central location, or machine room.

System, closed. A circulating system where a fluid is chilled in a closed vessel, circulated through a closed conduit or pipe system to a closed cooling unit and back to the closed chiller without being exposed to the atmosphere.

System, commercial. A refrigeration system installed in a commercial business, such as a meat market, super market and other like businesses.

System, compression. A refrigeration system in which pressures are raised by means of a mechanically operated compressor.

System, direct expansion. A refrigeration system in which the evaporators are fed directly from the liquid refrigerant line through a pressure reducing device such as a thermal expansion valve.

System, duct. An air distribution system in which air is directed to various areas through a system of metal or composition ducts.

System, flooded. A system whereby the liquid refrigerant is maintained at a desired level in an evaporator by means of a float valve or float switch controlled solenoid valve. Gas evaporated from the liquid is separated in a surge or accumulator tank, the gas being drawn off to the compressor and the liquid returning to the evaporator.

System, indirect. A cooling system utilizing a secondary refrigerant which is circulated to the area being cooled and returned to the primary equipment where it is chilled by the primary refrigerant.

System, industrial. A refrigerating system in an industrial plant such as a cold storage, icemaking, dairy, meat packing, etc. Usually a large system with relatively high concentration of machinery in a specified area.

System, off-peak. A refrigeration system designed to run during periods where plant loading is low. Refrigeration is accumulated by the formation of ice on various types of surfaces. During periods of high peak usage, the ice is melted to produce refrigerated chilled water for dairy use, air conditioning and other related loads. Electrical demand charges are saved by this type system as well as more fully utilizing smaller equipment by smoothing out the peaks.

System, recirculating. A refrigeration system in which liquid refrigerant is circulated by pump or pressure differences to the evaporators. More refrigerant is circulated than is evaporated thus assuring a wetted surface inside the evaporator with attendant high heat transfer. Excess liquid is separated in a suitable accumulator and returned to the circulation system.

System, refrigerating. A refrigeration system containing all the basic elements required to produce cold as well as recover the refrigerant for repeated use without loss.

System, self contained, (also unit system). A refrigeration system completely fabricated in a transportable condition so that it may be installed without any further connection of refrigerant lines.

Temperature. A level of heat. Temperature is not a quantity but an indication of the level at which heat may be added or extracted.

Temperature, ambient. The temperature of the air surrounding a room or an object.

Temperature, absolute. The temperature expressed in degrees above absolute zero.

Temperature, critical. The saturation temperature of a substance corresponding to the point where the properties of liquid and vapor are identical.

Temperature, dew point. The temperature at which moisture starts to condense out of the air as it is cooled providing the pressure is constant and no moisture added or taken away during the cooling process.

Temperature, dry bulb. The temperature of the air as measured by an ordinary thermometer of any type.

Temperature, saturation. The temperature of a fluid boiling point or condensation point at a given pressure.

Temperature, wet bulb. The temperature of evaporating water in an air stream. Normally, this temperature may be taken by a dry bulb thermometer bulb encased in a wetted wick. The air is moved rapidly over the wetted wick and the resultant temperature reading is the wet bulb temperature.

Thermocouple. The joining of two dissimilar metals into a junction. Application of heat causes a micro-current to flow. This current may be calibrated to read temperature. Also used to trigger a safety or monitor a pilot light in a heating system.

Thermometer. An instrument for measuring temperature.

Thermostat. A temperature sensing automatic temperature control device.

Ton (of refrigeration) American. A measure of refrigeration capacity; the amount of Btu required to melt one ton of water ice (2000 lbs.) in 24 hours at 32°F (0°C). One pound of ice melting absorbs 144 Btu. One ton equals 288,000 Btu in 24 hours or 12,000 Btu per hour or 200 Btu per minute.

Transmittance, thermal "U" factor. The time rate of heat flow from the fluid on the warm side of a barrier to the fluid on the cold side, per unit temperature difference; remembering that a fluid may be either a liquid or a gas.

Triple point. A state in which a substance may be in equilibrium in three phases, solid, liquid and gas.

Tube, capillary. A small bore tube used to meter refrigerant into an evaporator. Quantity of refrigerant and rate are governed by the bore and length of the tube. Used mainly in smaller tonnages such as domestic refrigerators, residential air conditioners, etc.

Tube, finned. A tube to which metallic fins have been added to increase the effective surface.

Turbulent flow. Flow of a fluid in a tube at a sufficient velocity that the flow ceases to be smooth but moves in several directions in its passage. Heat transfer can be increased by this type of flow.

Unloader. A device used on compressors to partially unload the compressor under reduced load. Usually accomplished by making selective cylinders of the compressor inoperative from a pumping standpoint.

Valve, back pressure. An automatic regulating valve designed to hold a set pressure on the coil in a refrigeration system by metering the suction gas to the compressor.

Valve, charging. A small valve placed in the circuit of a compression refrigeration cycle to which a refrigerant drum may be connected to feed refrigerant to the system when needed. Used to admit the initial charge on start-up or as make-up if leaks occur with refrigerant loss.

Valve, check. A piston or disc valve that permits travel of a fluid in only one direction.

Valve diaphragm. A hand valve utilizing a metal diaphragm instead of packing to prevent stem leadage. Motion is imparted to the closing mechanism of the valve by exerting pressure and flexing the diaphragm against the working parts.

Valve, dual relief. Two relief valves used to relieve pressure on a refrigeration system if it becomes dangerously high. The two valves are manifolded so that only one valve can be shut off at a time, always leaving one valve in service.

Valve, expansion, hand. A mechanically opened and closed valve containing a fine needle type seat to allow accurate setting to regulate flow through the valve.

Valve, thermal expansion. An expansion valve in a refrigeration system that regulated flow to the evaporator in response to the temperature of the suction pressure-temperature at the coil outlet.

Valve, float. A valve with an auxiliary float chamber with a valve operator attached to the float to regulate liquid level in a vessel.

Valve, hold back. A valve used in a refrigerating system to automatically keep pressure below a certain level at the compressor suction. Used to prevent overloading of the compressor during pull down periods.

Valve, king. The main liquid line valve in a refrigeration system. Normally located in the liquid outlet line from the receiver. Closing this valve stops all liquid refrigerant flow to the plant.

Valve, motorized. A valve operated by an electric motor. Motor may open and close valve or modulate between open and closed. Motor is normally responsive to a pressure or temperature control.

Valve, pneumatic. A valve with a controller operated by air pressure.

Valve, purge. A valve, usually at some high point in a refrigeration system used to purge off non condensible gases.

Valve, service. A valve normally installed at inlets and outlets of refrigeration equipment to permit isolation of the equipment for servicing.

Valve, solenoid. A valve with the stem operated by a solenoid plunger actuated from a solenoid coil. Valve mechanism is usually direct acting on small valves and pilot operated on larger valves.

Vapor. A gas particularly one near equilibrium with the liquid phase of the substance.

Vapor barrier. A material with high resistance to the passage of water vapor. Used in insulation applications to prevent the migration of water vapor into and through the insulation.

Viscosity. The property of semi-fluids, fluids and gases to resist an instantaneous change of shape or arrangement of parts.

Vital heat. Heat generated by vegetables and fruits in storage due to ripening.

Volatile liquid. A liquid which evaporates readily at atmospheric pressure and room temperature.

Volume, specific. The volume of a substance per unit mass, the reciprocal of density.

Water chiller. A device used in refrigeration to chill water with refrigeration.

Water vapor. A term used in air conditioning projections to refer to steam or moisture in the atmosphere.

Wet bulb depression. The difference between dry bulb and wet bulb temperature.

Zone. A division of a building or area served by an air conditioner or system. A large building will contain many zones.

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Appendix II

USEFUL CONVERSION FACTORS

TABLE A2.1. BRITISH TO METRIC AND METRIC TO BRITISH, ESPECIALLY RELATED TO FREEZER STORAGE AND OPERATIONAL REFRIGERATION

Length	1 m = 39.37 in. = 3.2808 ft
Area	1 sq m = 10.7638 sq ft
Volume	1 cu ft = 1,728 cu in. = 28.32 liters
Density	1 gm per cu m = 0.3613 lb per cu in. = 62.4238 lb per cu ft = 8.3454 lb per gal. (US)
Mass and weight	1 kg = 15432.4 grains = 2.2046 avoirdupois lb
Pressure	1 lb per sq in. = 0.0703 kg per sq cm = 8.0703 m column of water = 2.3066 ft column of water
Velocity	1 mile per hr = 1.4666 ft per sec = 0.8684 knots = 1.6094 km per hr. Standard gravity = 32.17 (ft) (sec^2) = 980.67 (cm) (sec^2)
Energy	1 US hp hr = 1,980,000 ft lb = 273,745 kg m = 2,544.65 Btu or 641,240 kgm cal.
Energy and heat	1 hp = 550 ft lb per sec = 76.0404 kg m per sec = 0.74565 kw.
Viscosity	1 gm per cm sec or dyne sec per sq cm poise = 100 lb sec per sq ft
Enthalpy	1 kg cal per kg = 1.8 Btu per lb. 1 Btu per lb = 0.5556 kg cal per kg.
Entropy	1 kg cal per (kg) (°C) = 1 Btu per (lb) (°F).
Thermal conductivity	1 Btu per (hr) (ft) (°F) = 1.487 kg cal per (hr) (m) (°C)
Coeff. of heat trans	1 Btu per hr per sq ft °F = 4.88 kg cal per (hr) per (sq m) per °C = 1 Chu[1] per (hr) (sq ft) per °C

[1] The centigrade heat unit Chu is the heat required to raise 1 lb of water 1°C and equals 1.8 Btu.

TABLE A2.2. CONVERSION TABLE—Engineering Gravitational Units: Units of Mass. Lb and Kg Units of Weight or Force, Lb_f and Kg_f

	British	Metric Equiv.
Time	1 (hr)	1 (hr)
Length	1 (in.)	25.4 (mm)
	(ft)	0.3048 (m)
	(mile)	1.610 (km)
Surface	1 (sq ft)	0.0929 (m^2)
Volume	1 (cu ft)	0.02832 (m^3)
	(qt)	0.9464 (l)
	(gal) (US)	3.785 (l)
	(Imp)	4.536 (l)
Mass	1 (lb)	0.4536 (kg)
Force or Weight	1 (lb$_f$)	0.4536 (kg$_f$)
Density	1 (lb)/(ft^3)	16.018 (kg)/(m^3)
	1 (lb)/(gal US)	0.1198 (gm)/(cm^3)
Pressure	1 (lb$_f$)/(ft^2)	4.883 (kg$_f$)/(m^2)
	1 (lb$_f$)/(in.^{2})	703.1 (kg$_f$)/(m^2)
Flow Rate	1 (ft^3)/(min)	1.699 (m^3)/(hr)
Dynamic Viscosity	1 (lb)/(hr)(ft)	1.488 (kg)/(hr)(m)
	1 (lb$_f$)(hr)/(ft^2)	4.88 (kg$_f$)(hr)/(m^2)
Kinematic Viscosity	1 (ft^2)/(hr)	0.0929 (m^2)/(hr)
Energy or Heat	1 (Btu)	0.2520 (kcal)
	1000 (Btu)	0.293 (kw)(hr)
	1000 (ft)/(lb$_f$)	0.3241 (kcal)
Power	1 (hp)	1.014 metric hp
	1 (Btu)/(sec)	1.054 (kw)
Temperature	1 °F	0.5556 (°C)
	°F = 1.80(°C) + 32°	
	°R = 459.7 + (°F)	
Specific Heat	1 (Btu)/(lb)(°F)	1.0 (kcal)/(kg)(°C)
Enthalpy, Latent Heat	1 (Btu)/(lb)	0.5556 (kcal)/(kg)
Thermal Conductivity	1 (Btu)/(hr)(ft)(°F)	1.487 (kcal)/(hr)(m)(°C)
Thermal Diffusivity	1 (ft^2)/(hr)	0.0929 (m^2)/(hr)
Heat Transf. Coeff.	1 (Btu)/(hr)(ft^2)(°F)	4.88 (kcal)/(hr)(m^2)(°C)
Refrigeration	1 ton (US)	3024 (kcal)/(hr)
	1 ton(Brit)	1.0 (kcal)/(sec)
	Metric	**British Equiv.**
Time	1 (hr)	1 (hr)
Length	1 (cm)	0.3937 (in.)
	1 (m)	3.2808 (ft)
	1 (km)	0.6214 (mile)
Surface	1 (m^2)	10.764 (ft^2)
Volume	1 (m^3)	35.314 (ft^3)
	1 (l)	1.057 (qt)
	1 (l)	0.2642 (gal US)
	1 (l)	0.220 (gal Imp)
Mass	1 (kg)	2.2046 (lb)

TABLE A2.2. *(Continued)*

	Metric	British Equiv.
Force or weight	1 (kg_f)	2.2046 (lb_f)
Density	1 (kg)/(m^3)	0.06243 (lb)/(ft^3)
	1 (gm)/(cm^3)	8.35 (lb)/(gal US)
Pressure	1 $(kg_f)/(m^2)$	0.2048 $(lb_f)/(ft^2)$
	1 $(kg_f)/(cm^2)$	14.22 $(lb_f)/(in.^2)$
Flow rate	1 (m^3)/(hr)	0.589 (ft^3)/(min)
Dynamic Viscosity	1 (kg)/(hr)(m)	0.672 (lb)/(hr)(ft)
	1 (kg_f)(hr)/(m^2)	0.205 (lb_f)(hr)/(ft^2)
Kinematic viscosity	1 (m^2)/(hr)	10.764 (ft^2)/(hr)
Energy or heat	1 (kcal)	3.968 (Btu)
	1 (kw)(hr)	3415 (Btu)
	1 (kcal)	3090 (ft)(lb_f)
Power	1 metric hp	0.9863 (hp)
	1 (kw)	0.9486 (Btu)/(sec)
Temperature	1 °C	1.800 (°F)
	°C = $\frac{5}{9}$(°F − 32°)	
	°K = 273.2 + (°C)	
Specific heat	1 (kcal)/(kg)(°C)	1.0 (Btu)/(lb)(°F)
Enthalpy, latent heat	1 (kcal)/(kg)	1.80 (Btu)/(lb)
Thermal conductivity	1 (kcal)/(hr)(m)(°C)	0.672 (Btu)/(hr)(ft)(°F)
Thermal diffusivity	1 (m^2)/(hr)	10.764 (ft^2)/(hr)
Heat transf. Coeff.	1 (kcal)/(hr)(m^2)(°C)	0.205 (Btu)/(hr)(ft^2)(°F)
Refrigeration	1000 (kcal)/(hr)	0.331 ton refrig (US)
	1 (kcal)/(sec)	1.0 ton refrig (Brit)
Standard gravity	32.17 (ft)/(sec^2)	980.67 (cm)/(sec^2)
Standard atmosphere	2116.8 $(lb_f)/(ft^2)$	10333 $(kg_f)/(m^3)$
1 Ton refrigeration	US 288,000 Btu/24 hr = 12,000 Btu/hr = 200 Btu/min US 0.840 ton refrig, Brit = 0.840 Frigorie Brit 342,800 Btu/24 hr = 14,285 Btu/hr = 238 Btu/min = 1 kcal/sec Brit 1.190 ton refrig, US = 1 Frigorie	
British thermal unit	777.5 ft-lb_f	
1 boiler horsepower	33,479 Btu/hr	
Pound (force) per square inch	0.0684 atm = 2.036 in. Hg = 51.3 mm Hg	
1 atmosphere	14.70 $lb_f/in.^2$ = 29.92 in. Hg = 760 mm Hg	
1 Centipoise	2.419 lb/ft-hr = 3.60 kg/m-hr	
1 Horsepower (US)	0.7457 kw = 42.44 Btu/min = 33.000 ft-lb_f/min = 550 ft-lb_f/sec	
1 Metric horsepower	75 kg_f-m/sec = 1 Ps = 1 chev-vap	
1 cubic foot	7.481 US gal = 28.315 l	
1 US gallon	0.1337 cu ft = 0.835 Imp gal	
1 Imperial gallon	0.1604 cu ft = 1.20 US gal	

Source: W.B. Van Arsdel 1967.

TABLE A2.3. RELATED TEMPERATURE CONVERSIONS—The Numbers Between Centigrade and Fahrenheit Columns Refer to the Temperature Either in Centigrade or Fahrenheit which is to be Converted to the Other Scale

C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F
−40.0	−40	−40.0	−23.3	−10	+14.0	−6.7	+20	+ 68.0	+10.0	+50	+122.0	+26.7	+ 80	+176.0
−39.4	−39	−38.2	−22.8	− 9	+15.8	−6.1	+21	+ 69.8	+10.6	+51	+123.8	+27.2	+ 81	+177.8
−38.9	−38	−36.4	−22.2	− 8	+17.6	−5.5	+22	+ 71.6	+11.1	+52	+125.6	+27.8	+ 82	+179.6
−38.3	−37	−34.6	−21.7	− 7	+19.4	−5.0	+23	+ 73.4	+11.7	+53	+127.4	+28.3	+ 83	+181.4
−37.8	−36	−32.8	−21.1	− 6	+21.2	−4.4	+24	+ 75.2	+12.2	+54	+129.2	+28.9	+ 84	+183.2
−37.2	−35	−31.0	−20.6	− 5	+23.0	−3.9	+25	+ 77.0	+12.8	+55	+131.0	+29.4	+ 85	+185.0
−36.7	−34	−29.2	−20.0	− 4	+24.8	−3.3	+26	+ 78.8	+13.3	+56	+132.8	+30.0	+ 86	+186.8
−36.1	−33	−27.4	−19.4	− 3	+26.6	−2.8	+27	+ 80.6	+13.9	+57	+134.6	+30.6	+ 87	+188.6
−35.6	−32	−25.6	−18.9	− 2	+28.4	−2.2	+28	+ 82.4	+14.4	+58	+136.4	+31.1	+ 88	+190.4
−35.0	−31	−23.8	−18.3	− 1	+30.2	−1.7	+29	+ 84.2	+15.0	+59	+138.2	+31.7	+ 89	+192.2
−34.4	−30	−22.0	−17.8	0	+32.0	−1.1	+30	+ 86.0	+15.6	+60	+140.0	+32.2	+ 90	+194.0
−33.9	−29	−20.2	−17.2	+ 1	+33.8	−0.6	+31	+ 87.8	+16.1	+61	+141.8	+32.8	+ 91	+195.8
−33.3	−28	−18.4	−16.7	+ 2	+35.6	.0	+32	+ 89.6	+16.7	+62	+143.6	+33.3	+ 92	+197.6
−32.8	−27	−16.6	−16.1	+ 3	+37.4	+0.6	+33	+ 91.4	+17.2	+63	+145.4	+33.9	+ 93	+199.4
−32.2	−26	−14.8	−15.6	+ 4	+39.2	+1.1	+34	+ 93.2	+17.8	+64	+147.2	+34.4	+ 94	+201.2
−31.7	−25	−13.0	−15.0	+ 5	+41.0	+1.7	+35	+ 95.0	+18.3	+65	+149.0	+35.0	+ 95	+203.0
−31.1	−24	−11.2	−14.4	+ 6	+42.8	+2.2	+36	+ 96.8	+18.9	+66	+150.8	+35.6	+ 96	+204.8
−30.6	−23	− 9.4	−13.9	+ 7	+44.6	+2.8	+37	+ 98.6	+19.4	+67	+152.6	+36.1	+ 97	+206.6
−30.0	−22	− 7.6	−13.3	+ 8	+46.4	+3.3	+38	+100.4	+20.0	+68	+154.4	+36.7	+ 98	+208.4
−29.4	−21	− 5.8	−12.8	+ 9	+48.2	+3.9	+39	+102.2	+20.6	+69	+156.2	+37.2	+ 99	+210.2
−28.9	−20	− 4.0	−12.2	+10	+50.0	+4.4	+40	+104.0	+21.1	+70	+158.0	+37.8	+100	+212.0
−28.3	−19	− 2.2	−11.7	+11	+51.8	+5.0	+41	+105.8	+21.7	+71	+159.8	+38.3	+101	+213.8
−27.8	−18	− 0.4	−11.1	+12	+53.6	+5.5	+42	+107.6	+22.2	+72	+161.6	+38.9	+102	+215.6
−27.2	−17	+ 1.4	−10.6	+13	+55.4	+6.1	+43	+109.4	+22.8	+73	+163.4	+39.4	+103	+217.4
−26.7	−16	+ 3.2	−10.0	+14	+57.2	+6.7	+44	+111.2	+23.3	+74	+165.2	+40.0	+104	+219.2
−26.1	−15	+ 5.0	− 9.4	+15	+59.0	+7.2	+45	+113.0	+23.9	+75	+167.0			
−25.6	−14	+ 6.8	− 8.9	+16	+60.8	+7.8	+46	+114.8	+24.4	+76	+168.8			
−25.0	−13	+ 8.6	− 8.3	+17	+62.6	+8.3	+47	+116.6	+25.0	+77	+170.6			
−24.4	−12	+10.4	− 7.8	+18	+64.4	+8.9	+48	+118.4	+25.6	+78	+172.4			
−23.9	−11	+12.2	− 7.2	+19	+66.2	+9.4	+49	+120.2	+26.1	+79	+174.2			

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